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Scientific, Technical and Economic Committee for Fisheries (STECF)

Evaluation of management plans

Evaluation of the multi-annual plan for the North Sea demersal stocks

(STECF-15-04)

Edited by Ernesto Jardim, Arina Motova and Finlay Scott

This report was reviewed by the STECF during its' 48th plenary meeting held from 13 to 17 April 2015 in Brussels, Belgium

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Abstract

The Expert Working Group meeting of the Scientific, Technical and Economic Committee for Fisheries EWG-15-02 on Evaluation of management plans. Evaluation of the multi-annual plan for the North Sea demersal stocks was held from 16-20 March 2015 in Ispra, Italy. The report was reviewed and endorsed by the STECF during its plenary meeting held from 13 to 17 April 2015 in Brussels (Belgium)

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Evaluation of management plans

Evaluation of the multi-annual plan for the North Sea demersal stocks

(STECF-15-04)

THIS REPORT WAS REVIEWED DURING THE PLENARY MEETING HELD IN BRUSSELS, BELGIUM, FROM 13 TO 17 APRIL 2015

BACKGROUND

Council Regulation (EU) No 1380/2013 on the new Common Fisheries Policy (CFP), has established new objectives and means for sustainable fisheries, including the objective of maintaining populations of harvested species above levels which can produce the maximum sustainable yield and achieving an exploitation rate consistent with this objective by 2015 and at the latest by 2020 for all stocks.

The CFP foresees the adoption of management measures in the context of multi-annual plans, which ensure transparency, predictability and stability within the process. While multi-annual plans were an option already in the CFP, after the 2013 reform they became a priority, according to Article 9 of Council Regulation (EU) No 1380/2013. The form and content of future multi-annual plans was subject to special analysis by a task force comprising the three main EU Institutions. The guidelines of this Task Force are in Council Document No 8529-14 PECHE 117 CODEC 1004.

Commission Proposal for a mixed fisheries multi-annual plan for the North Sea

Scope

The plan covers all demersal stocks caught entirely or partly in the Eastern Channel, North Sea, Skagerrak or Kattegat.

Objectives and targets:

a) To maintain stocks above the precautionary biomass.

b) For stocks for which ICES is able to provide advice on F_{MSY} ranges, to achieve a fishing mortality within those ranges by 2020 at the latest, and to maintain the mortalities within those ranges thereafter, taking into account technical interactions between fisheries.

c) For stocks for which ICES is unable to provide advice on F_{MSY} ranges, to achieve and maintain stocks at levels capable of producing catches which, according to scientific judgement based on considerations other than a full analytical assessment, are the highest among those that can be sustained in the long-term.

d) Ensure economic sustainability by managing under MSY to produce high and stable catches.

e) Contribute to the achievement of the objectives of the Marine Strategy Framework Directive.

Conservation measures

The Commission shall propose, each year, that total allowable catches are fixed for each of the species that are consistent with

a) Scientific advice on appropriate levels of fishing mortality for those stocks for which F_{MSY} advice is available.

b) Scientific advice on appropriate catches that might lead the stock to the objective b) above.

c) The avoidance of unwanted catches, taking into account scientific advice about mixed fisheries.

When allocating fishing opportunities to fishing operators, Member States shall ensure that choke effects can be avoided by the existing mechanisms (*inter alia*, *de minimis provisions*, inter-species quota flexibility, quota swaps).

Where appropriate the Member States will agree at regional level to establish fish stock recovery areas (Art. 8).

Safeguards

a) For any stock for which the spawning biomass is estimated to be below B_{pa}, conservation measures will be adopted that are consistent with rebuilding the stock to a spawning biomass greater than B_{pa} over a [n] year period.

b) For data limited stocks, conservation measures will be adopted to rebuild the stock whenever indicators (based on, *inter-alia,* catch, CPUE, surveys, recruitment indices) show that it is in a situation of low biomass and/or low reproductive capacity.

Technical measures

The Member States will agree at regional level on appropriate technical measures (Art. 7(2)) to contribute towards the achievement of the objectives of the plan, including:

a) Improving species-selectivity and/or size-selectivity in order to avoid unwanted catches.

b) Make obligatory or prohibit, as appropriate, the use of certain gear types after a certain percentage of the TAC has been taken.

c) Special measures to protect the prohibited species.

Review and updates

The performance of the plan in meeting its objectives will be assessed every [n] years.

Terms of reference

The STECF is requested to carry out quantitative analysis to support an impact assessment to assess the biological, economic and social consequences of implementing the various possible options described below, compared to fishing under Council Regulation (EU) No 1380/2013, including the landing obligation. It should also be assumed that the existing EU multi-annual plans for cod and for sole and plaice would no longer apply. STECF is requested to indicate the potential (dis)advantages, synergies and trade-offs of those options. STECF is also requested to compare the main options in terms of effectiveness, efficiency and coherence in achieving the objectives.

STECF should follow their guidelines for Impact Assessment reporting laid out in the STECF Protocols for Multi-annual Plan Impact Assessments (SG-MOS 10-01).

Detailed Request

STECF is requested to look at the following options:

a) What are the consequences of achieving, by 2016 and by 2020, fishing mortalities within the F_{MSY} ranges provided by ICES, with particular emphasis on the stocks of cod, haddock, whiting, saithe, sole, plaice and *Nephrops*?

b) In addition, for stocks that are below B_{pa}, what are the consequences for fishing opportunities in the mixed fisheries if the stocks are rebuilt to a spawning biomass greater than B_{pa} within i) 5 years or ii) 10 years (i.e. possible values of [n] in point 4 a)? (Considering that NS cod is near B_{lim}, the impact of this is likely to be driven largely at the rate at which you can recover cod).

c) Would by-catch stocks in the main fisheries be sufficiently protected through the management measures to achieve F_{MSY} on the species defining the fisheries (see point a), or would one or more need specific conservation measures? Can the stocks that are likely to need specific conservation measures be identified?

d) Based on the response to point c), what would be the advantages and disadvantages of grouping the by-catch stocks into an "other species" TAC? Are there any by-catch stocks for which individual TACs would be still recommended?

The management regimes in the intervening years between 2013 (the terminal data year) and 2016 (the first year of evaluation) should be taken to be as follows: 2014: agreed TACs; 2015: agreed TACs.

Indicators to be used in assessment of the North Sea multi-annual plan for comparison of defined options.

The STECF is asked to take into consideration the following indicators when commenting on the various questions 7(a) to (d) above:

Environmental:

1. Impacts on biodiversity
2. Abundance of main stocks
3. Evolution of the main predator and prey stocks

Economic by fleet segment and for SME:

1. GVA
2. Gross cash flow
3. Net profit
4. Profitability by fleet segment
5. Income by fleet segment
6. Supply to the market for each of the main species
7. Fuel consumption

Social

1. Employment by segment (differential impact between segments)

Governance

1. Expected monitoring and surveillance costs
2. Operator compliance (yes/no)

Possible impacts should be contrasted with the probable consequences of fishing the stocks according to the objectives laid out in Council Regulation (EU) No 1380/2013.

STECF is further invited to identify the most accurate indicators of progress (biological, economic, environmental and social) for this multi-annual plan.

STECF is asked to consider that one of the benefits it is anticipated this plan will achieve is to minimise any negative economic impacts of the landing obligation in the context of mixed-fisheries.

When the results from the above evaluations are available and the main advantages, synergies and trade-offs are considered, fisheries that would either be disproportionately affected, or could have significant effects on associated fisheries, should be mentioned. STECF is invited to suggest possible conservation measures (Art. 7) and / or incentives that could be introduced either in the multi-annual plan, or through delegation, to minimise the impact on those fisheries.

Request to the STECF

STECF is requested to review the report of the STECF Expert Working Group meeting, evaluate the findings and make any appropriate comments and recommendations.

In making its review, STECF applied the TORs listed in the background section above

Observations of the STECF

Preparatory discussions between STECF and DG MARE in Nov and Dec 2014 agreed a manageable programme of work and a mutual understanding of what could reasonably be delivered by a short EWG. Considerable preparation was carried out by the Chair of the EWG ahead of the meeting although it was clear that despite this effort, a growing list of additional requests meant that a complete analysis was unlikely to be achieved.

A Group of around 20 experts, observers and Commission officials met to complete the work and the EWG report outlines the approach and methods used to try to address the various questions. The basic approach was to compare the options with the baseline using simulations and employing four models, EwE, FCube, Simfish and Fishrent, to gain insights into different aspects of the plan. Values for the upper and lower ranges for F_{MSY} were provided by ICES. Annexes were provided with the EWG report describing in detail the different models used. To overcome issue created by not having a harvest control rule, an envelope approach was used (to simulate F_{low}/F_{upp}), and this essentially provided brackets to the potential results of the MAP.

STECF notes that an extensive analysis was carried out illustrated by a series of detailed figures comparing options with the baseline. The following table summarises the various management and fleet scenarios investigated.

Management scenario				**Fleet scenario**	
name	**runs**	**description**		**Lowest quota**	**Maximum economics**
CFP	cfp	Target:	F_{MSY}	ToR a)	
		Time to target:	2016		
CFP2020	cfp2020	Target:	F_{MSY}	ToR a)	
		Time to target:	2020		
MAP fast recovery	map.low	Target:	lower limit of F_{MSY} range	ToR a) and b)	
		Time to target:	2016		
		Safeguards:	B_{pa}		
		Recovery period:	5 years		
	map.upp	Target:	upper limit of F_{MSY} range		
		Time to target:	2016		
		Safeguards:	B_{pa}		
		Recovery period:	5 years		
MAP slow recovery	map10y.low	Target:	lower limit of F_{MSY} range	ToR b)	
		Time to target:	2016		

		Safeguards:	B_{pa}	
		Recovery period:	10 years	
	map10y.upp	Target:	upper limit of F_{MSY} range	
		Time to target:	2016	
		Safeguards:	B_{pa}	
		Recovery period:	10 years	

For a full detail description of the results it is necessary to consult the EWG report.

Some of the main findings from the modelling can be summarised as follows:

- In the short-term, differences between the performance of the CFP2020 scenario and the baseline are minor.
- If F is set at the upper limit of the F_{MSY} range, short-term catches are higher, but biomasses are lower and there is increased risk to B_{lim} for some stocks. More effort is required and there may be a negative impact on profitability. Setting F at the lower limit inverts these results.
- Observing the impact in a 2020 snapshot shows that fishing at the upper limit of the F_{MSY} range leads to increased risk to B_{lim} in cod and sole, there are larger landings for the fleets but these may be associated with higher costs.
- In the long-term, fishing at the higher limit of the F_{MSY} range generates higher catches but keeps biomasses lower and increases risks to the stocks. Effort has to be sustained at a higher level. In scenarios maximising revenues, fishing at the upper limit of the F_{MSY} range requires higher effort whereas at the lower limit revenues are smaller but so too is the effort required. The impact on profitability has not been possible to ascertain.
- In terms of employment not all fleets exhibit the same dependency on the species that drive the fisheries. Under 10m vessels have high employment but low dependency whereas large demersal vessels have high employment and high dependency. A few specialist fleets exhibit low employment but high dependency.
- The use of F_{MSY} ranges gives scope to reconcile TACs for different species so that they become closer to being consistent with F_{MSY}.
- The impact on most stocks of short (5 year) or long (10 year) recovery is not very pronounced except for cod where the risk is higher if recovery is protracted. In the short-term, impacts on the fleets are limited. On balance fast recovery for cod seems preferable.
- Bringing fishing levels closer to the lower limit of the F_{MSY} ranges could increase the influence of biological interactions in the system through natural mortality, partly driven by prey-predator interactions, playing a bigger part in influencing stock abundance. Conversely fishing at the upper limit of the F_{MSY} range initially generates higher catches but tends to suppress biomass and is only possible with increased effort and associated increased costs.

STECF CONSIDERATIONS

STECF notes that the overarching reason for conducting these analyses was to provide guidance on whether the proposed MAP as set out in the background above represented an improvement on simply adopting the basic regulation. As such an important task for the EWG was to identify positive or negative aspects of the MAP which could inform decisions one way or the other.

Protocols for impact assessment of MAPs have in the past been discussed and agreed by (STECF 10-06a). In view of the recent developments, the contents of MAPs and the process to design a regulation proposal have changed, these protocols are outdated and require revision, although some of the elements are still relevant and should be kept.

STECF wishes to commend the EWG on the considerable effort and significant contribution made towards assessing the impact of the North Sea Multi-annual plan. The basic request to carry out an impact assessment using as a baseline the CFP regulation (Council Regulation (EU) No 1380/2013,) including the landing obligation was, from the outset, complex because of difficulties in interpreting the regulation and in modelling the landing obligation. STECF notes, that owing to time constraints, model limitations and considerable uncertainty in the future dynamics of biological, technical and economic systems arising from incoming management policies, a number of questions remain unanswered. The difficulties of the EWG were exacerbated by, the requirement for a fundamental change in the evaluation process, namely a shift away from evaluating candidate harvest control rules to the use of an 'envelope' approach comparing contrasted options with the baseline case (basic regulation). Belated updates of key inputs (F_{MSY} ranges values) also created difficulties.

STECF notes that the lack of harvest control rules is not simply a technical issue affecting the evaluation, rather there are implications for the future management of the fisheries. Experience over a number of years have shown that HCRs provide a mechanism to constrain large scale fluctuations in catch and confer the advantages of stabilisation and limiting the impacts of the uncertainties associated with the stock assessment process.

One of the principle elements of the outline North Sea MAP is the inclusion of F_{MSY} ranges for each species. The use of ranges represents a development beyond the basic CFP regulation which the EWG analysis was able to focus on. Recognising that it is not possible to simultaneously achieve single species F_{MSY} point estimates for all species in a mixed fishery, F_{MSY} ranges potentially provide a tool allowing for better reconciliation between fishing opportunities and the objectives of the CFP. Values for the F_{MSY} ranges were provided by ICES (Special Request advice March 2015), based on the general principle that the range should generate high yield (designed to deliver no more than a 5% reduction on MSY).

An important outcome from the EWG analysis is that the F_{MSY} range approach does appear to confer flexibility which could assist in reconciling difficulties arising in the mixed fishery context. STECF further notes that persistent fishing at upper limit of the F_{MSY} range across a range of stocks may not be precautionary and may have broader ecosystem impacts. For a mixed fishery as a whole, utilizing upper limit of the F_{MSY} range for a substantial proportion of the stocks may impair the economic performance of the fleet in the long-term. In order to avoid situations of this type developing, it will be important that decisions taken on fishing opportunities are carefully considered and rationally planned. Clearly, if the Council responded to annual advice by systematically agreeing TACs corresponding to upper limit of the F_{MSY} range, problems could quickly emerge. STECF draws attention to the fact that the ICES advice also includes important considerations as well as average long-term yield for fishing above or below F_{MSY}. In a single-species context fishing above F_{MSY} implies reduced stock biomass and this may be substantial where the upper limit of the F_{MSY} range (F_{upper}) is much higher than F_{MSY} So in utilizing F_{MSY} ranges there are more advantages to fishing between F_{MSY} and the lower limit of the F_{MSY} range (Flower) than between F_{MSY} and F_{upper}".. STECF concludes that to maximise the likelihood of achieving the objectives of the CFP, setting fishing opportunities at the level of the upper limit of the F_{MSY} range should only be applied only in exceptional circumstances.

STECF notes that the advisory process will need to include a more explicit recognition of the multi-species and multi-gear nature of fisheries in the North Sea. Discussions in STECF EWGs dealing with the Landing Obligation (CFP Art. 15) have identified some technical or behavioural changes that might occur. These include adoption of novel gears, increased mesh size, greater flexibility in quota transfer and adjustments in areas fished. In addition to the difficulty of predicting what responses will take place, the lack of models which can adequately capture some of these dynamics limited the scope for analysis. Given the uncertainties, STECF cannot provide an exhaustive evaluation on what the impact of the landing obligation might be on the likely performance of the MAP, as compared with application of the basic regulation.

STECF notes that widespread introduction of technical measures leading to adjustments in exploitation pattern (eg. reduced catches of unwanted small fish) would result in changes to F_{MSY} and likely changes to the ranges. At this stage it is not clear at what pace such changes would take place if at all. Consequently, STECF considers it important that the MAP be subject to a revision three to five years after the implementation to take account of the impact that the LO may have on the coherence between the MAP provisions and the CFP objectives

The MAP as conceived focusses on a number of species that drive the fisheries, which generally occur in mixed fisheries containing varying proportions of other species, referred to as “by-catch” in the following text. To evaluate the question of whether management of the species that drive the fisheries adequately allows for the management of by-catch species, the EWG carried out an analysis of correlations between catches of driver species identified in the plan and a variety of by-catch species. The analysis suggested only limited correlation. In view of this, the STECF notes that it is unlikely that relying on the TAC of the driver species to manage other species will be effective, in accordance with CFP requirements. STECF however notes that when analysis was performed at the fleet level, there were more obvious correlations, suggesting some scope to use fleet related management measures for the driver species as a way of managing some of the bycatch species.

Based on the observations of the EWG, STECF notes that grouping a number of single species TACs into a combined TAC could introduce additional flexibility in the management of this system. However, there is an increase potential to overexploit some stocks by re-allocating catches within the mix, to species which may not be able to cope with such exploitation levels. The EWG identified a set of mitigation principles (e.g. not grouping species with very different market values) which STECF agrees need to be considered if combining single species TACs is finally included in a management plan. STECF concludes that an increase level of monitoring (e.g. collection of landings and discards information, survey indices, etc.) and enforcement activities would be essential to evaluate if any of the species in the combined TAC are being overfished. The EWG analysis also examined the efficacy of short or long recovery times. Owing to the status of the cod stock this became the main driver of many management decisions and the species effectively operates as a choke to achieving full potential of the fishery as a whole. STECF notes that short recovery times reduced potential choke effects quicker.

STECF notes that regional bodies will play a major role on the implementation of the MAPs, through the regionalization of some management measures. At the moment the extent to which the regional groups will be involved is unknown. One option might be for the Regional Group to develop mixed fisheries recommendations based around a more balanced use of the MAP provisions taking due regard for long-term high yield and maintenance of stocks above the safeguards. Such an approach would require the Regional Group to have access to suitably tailored mixed fishery advice. STECF suggests that discussion between the Commission, Regional Groups, stakeholders and science providers is urgently needed to scope out requirements. This would ensure efficient use of sparse technical resources and build transparency into the process.

Finally, STECF draws attention to the need to consider the content of the MAP in the context of existing management of North Sea shared stocks through long-term management plans agreed with Norway. It is difficult to see how parallel arrangements could effectively operate without generating confusion to managers and stakeholders and placing unreasonable expectations on the science community. There is a need for dialogue in order to align the processes and build coherence.

CONCLUSIONS OF THE STECF

STECF concludes from the EWG analysis that:

1. The F_{MSY} range approach appears to confer flexibility to setting fishing opportunities, which could help reconcile difficulties arising in a mixed fishery context, and the biomass safeguards adopted by ICES to advise on F_{MSY} ranges provide an important level of protection against over-fishing; therefore the NSMAP proposals represent an improvement on simply adopting the provisions of basic regulation.
2. There is an increased risk of over-exploitation if fishing opportunities are set in line with the upper limits of the F_{MSY} ranges, particularly if several stocks in a mixed fishery are involved.
3. The use of the F_{MSY} range approach should only be employed when informed by objective mixed fishery advice which demonstrates that attaining F_{msy} for the key driver species can not be achieved simultaneously and the the application of F_{msy} ranges are necessary to better reconcile mixed fisheries issues. In the absence of such information, then fishing opportunities should be set in accordance with single species F_{msy} advice.
4. For Mixed fisheries, relying on the TACs of the species that drive the fishery is unlikely to be effective at controlling the fishing mortality on other species caught in the same fisheries.
5. Grouping the fishing opportunities for a number of stocks into a combined TAC could introduce additional flexibility for vessel operators to manage their individual fishing opportunities. However, to do so, would mean that there is an increased potential to overexploit some of those stocks. This could occur if the cumulative TAC is used to target only a proportion of species included in the combined TAC thus catches of individual species could be significantly higher than would implied by their single species TAC. Such overexploitation could be particularly severe if large removals of species that are already over-exploited or have low productivity occurs.

REPORT TO THE STECF

EXPERT WORKING GROUP ON
Evaluation of Management plans
Evaluation of the multi-annual management plan for the North Sea demersal stocks
(EWG-15-02)

Ispra, Italy, 16-20 March 2015

1 EXECUTIVE SUMMARY

The Council Regulation (EU) No 1380/2013 on the new Common Fisheries Policy (CFP) foresees the adoption of management measures in the context of multi-annual plans (MAPs). While multi-annual plans were an option already in the previous CFP, after the 2013 reform they became a priority, according to Article 9 of Council Regulation (EU) No 1380/2013. The form and content of future multi-annual plans was subject to special analysis by a task force comprising the three main EU Institutions. Under this context, DGMARE has to design MAPs and carry out impact assessments (IA) on the different options available for their implementation. STECF has been involved in this process by providing scientific advice to DGMARE, which is afterwards used as the quantitative basis for the IA.With regards to the proposal for a MAP covering the demersal fisheries in the North Sea, the STECF was requested to carry out quantitative analysis to support an impact assessment to assess the biological, economic and social consequences of implementing the various possible options described below, compared to fishing under Council Regulation (EU) No 1380/2013, including the landing obligation. It should also be assumed that the existing EU multi-annual plans for cod and for sole and plaice would no longer apply. STECF is requested to indicate the potential (dis)advantages, synergies and trade-offs of those options. Detailed ToR can be found on the body of the report.

Following the best practices in the field of scientific policy advice the evaluation of the regulation proposal was carried out using simulation testing. However, the ToRs set a number of questions that were not possible to approach using a single comprehensive model to run all the simulations required. The settings are quite complex and the forecasts require strong assumptions to be made, in particular due to the introduction of the last revision of the CFP and the effects the landings obligations will have on the fleets' behavior. On the other hand the removal of harvest control rules (HCRs) from the MAP legislation, introduced an extra level of complexity to be simulated, which was new for the current model frameworks and techniques. The new framework for MAPs required a shift in the analysis' concepts, from a situation where scientists were required to assist policy makers designing the MAP, in the sense of studying the trade-offs of candidate HCRs, to a situation where scientists are required to evaluate and give advice on the added value of implementing a MAP when compared with a baseline. To deal with this new framework a new approach had to be developed in a very short time frame.

The EWG used several models available and defined the scenarios in forms that were expected to provide the necessary information to support the advice. The time frame available was very limited, which conditioned the possibility to test different options to implement the scenarios in each model. Four models were available; an Ecopath with Ecosim (EwE), Fcube, Simfish and Fishrent. These models implement very distinct concepts of the marine system: EwE is an spatial ecological model with a strong emphasis on the energy transfer across trophic levels which builds on top a mixed fisheries model; FCube is a mixed fisheries simulation model with a focus on technical interactions; Simfish is a spatial bio-economic model that within the constraints of different management options, optimizes the effort allocation across fleets to get the maximum economic rent: and Fishrent is similar to Simfish without the spatial component.

The evaluation provides a general comparison of the expected outcomes of managing this fishery under the basic CFP regulation or under a specific plan that incorporates the available knowledge on species and fleet interactions. This knowledge was partial and did not allow a full evaluation of the risks associated by all management options. The evaluation was also limited by the lack of a HCR. As such estimations of future performance and the associated risks can only be carried out by assuming what the decision making body will do when confronted with various signals on stock status. The final ability of all of the management options under analysis to deliver the objectives will be contingent on management decisions deviating or not for those implicit in the plans analyzed. Finally, the impact of the Landings Obligation (LO) cannot be precisely evaluated at this time. The likely changes in effort allocation, fleet catchability and selectivity, and catch composition cannot be predicted at the moment given the available information and our knowledge of the fleet dynamics, but also given the existing uncertainty in the precise implementation of the LO policy in some fisheries. The analyses presented here have assumed that the LO policy will be implemented fully.

The EWG concluded that attempts at simultaneously managing a number of stocks at precisely F_{MSY} levels is bound to fail, given the levels of natural variability in fish populations, and the dynamics of fleet activity. Inconsistencies between targets for different stocks appear to be larger for the baseline scenarios, which attempt to achieve F_{MSY} levels of exploitation for all stocks. Fishing opportunities can be reconcile better when the flexibility provided by the F_{MSY} ranges is used.

Given the complex interactions between fleets and stocks, and the narrow range of balance across all stocks, protections against implementation error and ensure safe biomass levels for all stocks need to be built into the management system. Biomass safeguards for all stocks should still be maintained and should provide a basic level of protection in this case.

Adopting F_{MSY} ranges could in some cases increase the risk of overfishing across some or all stocks, particularly if a decision is taken to fish at the upper levels of those ranges. The benefits that could be obtained, in terms of flexibility and adaptability, would then be lost as inconsistencies on status and management needs across stocks would likely increase. The probability of stocks falling below B_{pa}/B_{lim} reference points appears to be substantially higher. In the long term, the fishery would be expected to be less profitable, as catch rates would decrease while exploitation costs remain constant.

Increasing the flexibility of the system, while potentially allowing it to better accommodate to the tensions and contradictions expected from such a wide range of fleets and stocks operating in combination, will also introduce greater uncertainty in our ability to forecast the responses of those stocks to future exploitation rates and the responses of all fleets to changes in fishing opportunities. The constraints in annual changes in TAC, present in past regulations, helped keeping the system stable with advantages both for the fleet and the stocks and could be maintained on future regulations.

The combination of changes in the basis for advice, either under the CFP rules or MAPs, will require adaptation of the advisory process to include a more explicit recognition of the multi-species and multi-gear nature of this fishery.

Bringing fishing levels closer to F_{MSY} could increase the influence of biological interactions in the system. Natural mortality, partly driven by prey-predator interactions, would play a bigger part in stock abundance. Population dynamics and seasonal dynamics of the fishery under the new conditions would have to be further investigated to better understand the increasing role of natural relationships in the North Sea fish stocks.

Relying on the management of the species that drive the fisheries to manage the non-driver species, to the levels of conservation required by the CFP is likely to be ineffective. Most, if not all, fleet dynamics regarding the target species occur at the fleet level, which are not directly affected by the definition of fishing opportunities.

Grouping a number of single species TACs could introduce additional flexibility in the management of this system. However, the trade-off is that the potential to overexploit some stocks appears to increase. A set of mitigation principles were identified which should be considered if grouping of single species TACs is finally included in a management plan. Intense and strict monitoring will be essential to ensure that non-target species, or those less easily identified, are not overfished. The inclusion of fishing effort controls should also be considered in this case.

2 BACKGROUND

Council Regulation (EU) No 1380/2013 on the new Common Fisheries Policy (CFP) has established new objectives and means for sustainable fisheries, including the objective of maintaining populations of harvested species above levels which can produce the maximum sustainable yield and achieving an exploitation rate consistent with this objective by 2015 and at the latest by 2020 for all stocks.

The CFP foresees the adoption of management measures in the context of multi-annual plans, which ensure transparency, predictability and stability within the process. While multi-annual plans were an option already in the CFP, after the 2013 reform they became a priority, according to Article 9 of Council Regulation (EU) No 1380/2013. The form and content of future multi-annual plans was subject to special analysis by a task force comprising the three main EU Institutions. The guidelines of this Task Force are in Council Document No 8529-14 PECHE 117 CODEC 1004.

2.1 Commission Proposal for a mixed fisheries multi-annual plan for the North Sea

Scope

The plan covers all demersal stocks caught entirely or partly in the Eastern Channel, North Sea, Skagerrak or Kattegat.

Objectives and targets:

a) To maintain stocks above the precautionary biomass.
b) For stocks for which ICES is able to provide advice on FMSY ranges, to achieve a fishing mortality within those ranges by 2020 at the latest, and to maintain the mortalities within those ranges thereafter, taking into account technical interactions between fisheries.
c) For stocks for which ICES is unable to provide advice on FMSY ranges, to achieve and maintain stocks at levels capable of producing catches which, according to scientific judgement based on considerations other than a full analytical assessment, are the highest among those that can be sustained in the long term.
d) Ensure economic sustainability by managing under MSY to produce high and stable catches.
e) Contribute to the achievement of the objectives of the Marine Strategy Framework Directive.

Conservation measures

The Commission shall propose, each year, that total allowable catches are fixed for each of the species that are consistent with

a) Scientific advice on appropriate levels of fishing mortality for those stocks for which F_{MSY} advice is available.
b) Scientific advice on appropriate catches that might lead the stock to the objective b) above.
c) The avoidance of unwanted catches, taking into account scientific advice about mixed fisheries.

When allocating fishing opportunities to fishing operators, Member States shall ensure that choke effects can be avoided by the existing mechanisms (*inter alia*, *de minimis provisions*, inter-species quota flexibility, quota swaps).

Where appropriate the Member States will agree at regional level to establish fish stock recovery areas (Art. 8).

Safeguards

a) For any stock for which the spawning biomass is estimated to be below B_{pa}, conservation measures will be adopted that are consistent with rebuilding the stock to a spawning biomass greater than B_{pa} over a [n] year period.

b) For data limited stocks, conservation measures will be adopted to rebuild the stock whenever indicators (based on, *inter-alia*, catch, CPUE, surveys, recruitment indices) show that it is in a situation of low biomass and/or low reproductive capacity.

Technical measures

The Member States will agree at regional level on appropriate technical measures (Art. 7(2)) to contribute towards the achievement of the objectives of the plan, including:

a) Improving species-selectivity and/or size-selectivity in order to avoid unwanted catches.

b) Make obligatory or prohibit, as appropriate, the use of certain gear types after a certain percentage of the TAC has been taken.

c) Special measures to protect the prohibited species.

Review and updates

The performance of the plan in meeting its objectives will be assessed every [n] years.

2.2 Terms of reference

The STECF is requested to carry out quantitative analysis to support an impact assessment to assess the biological, economic and social consequences of implementing the various possible options described below, compared to fishing under Council Regulation (EU) No 1380/2013, including the landing obligation. It should also be assumed that the existing EU multi-annual plans for cod and for sole and plaice would no longer apply. STECF is requested to indicate the potential (dis)advantages, synergies and trade-offs of those options. STECF is also requested to compare the main options in terms of effectiveness, efficiency and coherence in achieving the objectives.

STECF should follow their guidelines for Impact Assessment reporting laid out in the STECF Protocols for Multi-annual Plan Impact Assessments (SG-MOS 10-01).

Detailed Request

STECF is requested to look at the following options:

a) What are the consequences of achieving, by 2016 and by 2020, fishing mortalities within the F_{MSY} ranges provided by ICES, with particular emphasis on the stocks of cod, haddock, whiting, saithe, sole, plaice and *Nephrops*?

b) In addition, for stocks that are below B_{pa}, what are the consequences for fishing opportunities in the mixed fisheries if the stocks are rebuilt to a spawning biomass greater than B_{pa} within i) 5 years or ii) 10 years (i.e. possible values of [n] in point 4 a)? (Considering that NS cod is near B_{lim}, the impact of this is likely to be driven largely at the rate at which you can recover cod).

c) Would by-catch stocks in the main fisheries be sufficiently protected through the management measures to achieve F_{MSY} on the species defining the fisheries (see point a), or would one or more need specific conservation measures? Can the stocks that are likely to need specific conservation measures be identified?

d) Based on the response to point c), what would be the advantages and disadvantages of grouping the by-catch stocks into an "other species" TAC? Are there any by-catch stocks for which individual TACs would be still recommended?

The management regimes in the intervening years between 2013 (the terminal data year) and 2016 (the first year of evaluation) should be taken to be as follows: 2014: agreed TACs; 2015: agreed TACs.

Indicators to be used in assessment of the North Sea multi-annual plan for comparison of defined options.

The STECF is asked to take into consideration the following indicators when commenting on the various questions 7(a) to (d) above:

Environmental:

1. Impacts on biodiversity
2. Abundance of main stocks
3. Evolution of the main predator and prey stocks

Economic by fleet segment and for SME:

1. GVA
2. Gross cash flow
3. Net profit
4. Profitability by fleet segment
5. Income by fleet segment
6. Supply to the market for each of the main species
7. Fuel consumption

Social

1. Employment by segment (differential impact between segments)

Governance

1. Expected monitoring and surveillance costs
2. Operator compliance (yes/no)

Possible impacts should be contrasted with the probable consequences of fishing the stocks according to the objectives laid out in Council Regulation (EU) No 1380/2013.

STECF is further invited to identify the most accurate indicators of progress (biological, economic, environmental and social) for this multi-annual plan.

STECF is asked to consider that one of the benefits it is anticipated this plan will achieve is to minimise any negative economic impacts of the landing obligation in the context of mixed-fisheries.

When the results from the above evaluations are available and the main advantages, synergies and trade-offs are considered, fisheries that would either be disproportionately affected, or could have significant effects on associated fisheries, should be mentioned. STECF is invited to suggest possible conservation measures (Art. 7) and / or incentives that could be introduced either in the multi-annual plan, or through delegation, to minimise the impact on those fisheries.

3 INTRODUCTION

The STECF has substantial experience in providing advice on multiannual fishery management plans and has developed guidelines specifically designed (STECF, 2010) to provide DG-MARE with the advice it needs to prepare impact assessment reports to accompany proposals for such plans. In developing this process, the STECF was able to draw on scientific publications and experience in other parts of the world as well as in Europe. The recently reformed CFP, and the agreement between the Council and the Parliament on multiannual plans have both led to substantial changes in the form of multi-annual plans and thus also for the nature of the advice that STECF is requested to provide.

The new CFP introduces the requirement for multi-annual plans to cover mixed fisheries and to take into account knowledge about the interactions between fish stocks, fisheries and marine ecosystems. There is no precedent for the use of plans of this complexity anywhere in the world. While there is some research work relevant to this issue currently in progress in Europe, it means that there is as yet, very little material available to inform the work needed to assess the potential effects of such plans. As a result, the assessment of options for such plans will be a complex process which will require considerable scientific innovation.

The Lisbon treaty required the use of the co-decision process for EU fisheries legislation for the first time. A dispensation from this was granted for the setting of annual TAC regulations due to the need to implement these quickly, but other fisheries legislation now needs to be agreed with the European Parliament as well as the Council. This led to a legal & technical dispute over responsibility for multi-annual plans, as these were used for setting annual TACs but doing so in a more long-term framework. This dispute was eventually resolved through negotiation between the Commission, the Council and the Parliament which led to a new agreed framework for multiannual plans (Anon. 2014). From the perspective of STECF, and its ability to provide advice based on quantitative analyses of the likely consequences of such plans, a key element is the absence of defined harvest control rules. These have been the core element of previous multiannual plans and have been important to their success in both supporting sustainable exploitation of stocks, and ensuring stability of fishing opportunities for industry. The agreement also introduced the idea of ranges for F_{MSY} rather than single values, in the case of mixed fisheries.

While the omission of harvest control rules from multiannual plans may have helped resolve the inter-institutional dispute over multiannual plans, this decision has implications for both the potential effectiveness of the plans and for the assessment of their effects. A harvest rule determines what the TAC should be each year depending on the state of the stock relative to reference points and the objectives of the plan. It is relatively straightforward to assess the possible impacts of a simple harvest control rule by applying the rule to mathematical simulations of the fish populations. In the absence of such a well-defined rule, the assessment requires assumptions about how the Council will set TACs. By nature, this is very difficult to anticipate, and this has meant that there is greater uncertainty in the assessments than has previously been the case, and hence there is probably also greater risk to the stocks inherent in managing in this way.

In general, in place of specified harvest control rules, there will be a requirement to maintain the fishing mortality on each stock with the F-MSY range for each stock. This has also caused additional uncertainty in the assessments conducted by the current EWG, not least because the ranges have not yet been finalised for all stocks, with some being determined by an ICES advice drafting group which met at the same time as this EWG. In principle, the specification of FMSY ranges for each stock allows some flexibility to reduce mismatches due to mixed fishery effects or to allow for greater stability of yields, without jeopard9ising the overall objective of achieving maximum sustainable yield. It remains to be seen how this will work in practice. In particular, there may be pressure to select TACs based on the upper bound of the FMSY range for each stock. To do this continually for all stocks would disregard the flexibility that the ranges offer, with a greater overall risk to the stocks.

The following example illustrates the main issues relating to providing advice on fishing opportunities for stocks that are exploited in mixed fisheries and how F_{MSY} ranges might be used to give such advice.

Potential approach to align catch advice with F_{MSY} ranges in mixed fisheries

As an illustration of the interpretation and potential use of F_{MSY} ranges to provide catch advice for mixed fisheries, Figure 3.1 displays, for the six main North Sea stocks, the F_{MSY} range relative to the estimated F on the stock in 2013 (F_{2013}) as estimated by ICES in 2014. Therefore, Figure 3.1 represents the situation where catch advice for 2015 is to be based on stock assessments undertaken in 2014 and which include data up to 2013.

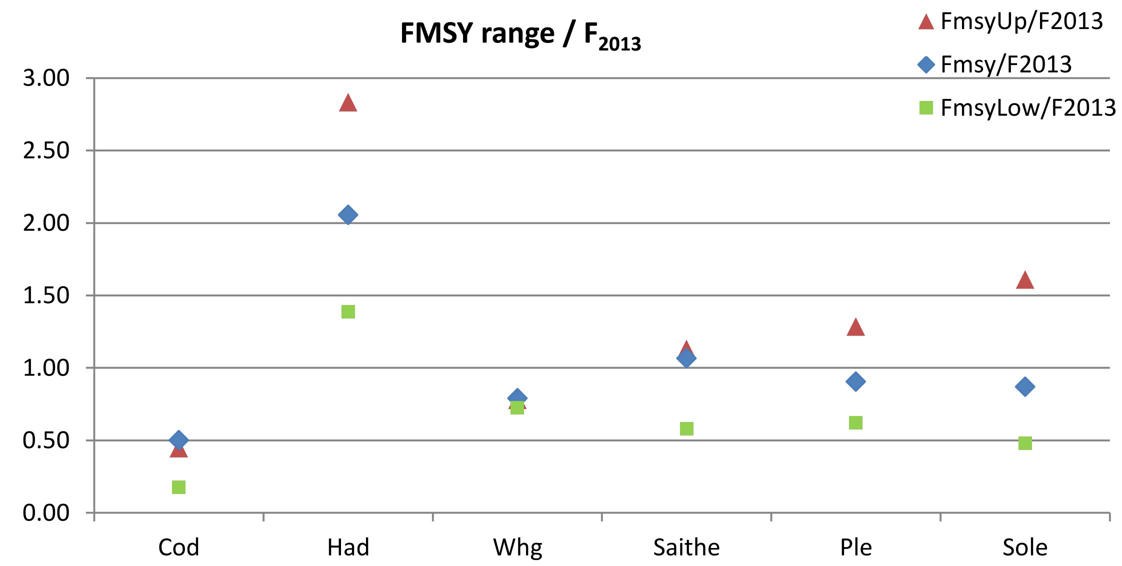


Figure 3.1. F_{MSY} ranges / F_{2013}, for the six main North Sea stocks. FmsyUp and FmsyLow are the upper and lower limits of the F_{MSY} ranges respectively for each species[1].

For each species, the values in the vertical axis of the figure represent the multiplier of fishing mortality needed to go from F_{2013} (1.0) to the F_{MSY} range for that species. Therefore, if for a species the value 1.0 is inside/outside the range in the figure, it means that F_{2013} is inside/outside the F_{MSY} range for that species. Hence for saithe, plaice and sole F_{2013} falls within their F_{MSY} ranges, and the F-multipliers overlap for the three species.. Defining F_{MSY} or the F_{MSY} range for whiting is challenging, but the provisional estimates as used by the Expert group nevertheless fall within with the F multipliers for saithe, plaice and sole. Figure 3.1 suggests that the main issues with advising appropriate catch options for 2015 are associated with determining the most appropriate F-multiplier for the cod and haddock stocks. For cod, a strong reduction from F_{2013} is needed to reach a value within the F_{MSY} range, whereas the opposite is true for haddock. Additionally, the F_{MSY} ranges for cod and haddock (relative to F_{2013}) have minimal overlap with the ranges for the other species. Such discrepancies

[1] ICES has not formally defined B_{pa} for whiting. A provisional B_{pa} for whiting was computed by the expert group by multiplying the ICES value for B_{lim} by 1.4.

highlight the difficulties faced in providing appropriate F-based catch advice for the management of the mixed fisheries.

If the ranges for the different species in Figure 3.1 had a common area where they all overlapped, that overlap area could provide a logical common range of F multipliers that could be applied to F_{2013} in order to give catch advice for 2015. TACs based on F-based catch advice derived using the overlap area might, in principle, be expected to result in fewer mixed fisheries problems in 2015, given that such TACs would correspond to similar (or even equal) changes in F for all species; in practical terms, this would mean that roughly similar increases or reductions in effort would be expected to be needed for all species (assuming no selection/catchability changes between 2013 and 2015).

Unfortunately, the ranges for the different species in Figure 3.1, do not have an area where they all overlap and this makes giving balanced catch advice (from a mixed fisheries perspective) for 2015 more problematic. Nevertheless Figure 1 suggests that if the agreed TACs for 2015 are based on catch advice derived using the lower end of the F_{MSY} range for haddock and the upper end for cod, the TACs for both species would be more in line with the relative changes in fishing mortality required to take those TACs compared to the situation where e.g., the TACs were based on their point estimates of F_{MSY} or the upper or lower bounds of their F_{MSY} ranges. By having more balanced TACs, one might hope that there is a better chance that the realised catches are closer to the TACs set for each species and, hence, than the realised F values are also closer to those expected by the agreed TACs.

In contrast to the above, Figure 3.1 also suggests that basing the catch advice for 2015 for haddock towards the upper end of its F_{MSY} range would likely increase mixed fisheries problems, as the increase in effort needed to catch the haddock quota would be strongly out of line with the changes in effort required to catch the quotas of other species (again assuming no selection/catchability changes between 2013 and 2015). In this situation, the haddock TAC may not be fully utilized if the effective effort cannot increase by the required amount to catch it and, furthermore, the risk of overexploiting other species that are caught together with haddock is likely to increase.

As the above arguments are largely intuitive and have not been tested through simulation, they should be treated with caution. Additional insights by mixed fisheries experts together with appropriate simulation-testing is required to gain further insight into the utility of such an approach.

In summary, the form and context for the intended North Sea multiannual plan have changed considerably following the implementation of the new basic regulation for the CFP and the agreement on management plans between the European Parliament and the Council. The changes include the need to account for mixed-fisheries and multi-species interactions, the use of ranges for F-MSY and the non-inclusion of harvest control rules. Despite this, the time available to STECF to assess options for the plan has been much less than usual, and the results of the assessments are limited by what could be done in the time available rather than the full assessment that the task requires.

Guidelines to support impact assessments of management plans

The STECF was requested to undertake a quantitative analysis to support an impact assessment of the North Sea multi-annual plan following the guidelines for impact assessment reporting laid out in the STECF Protocols for Multi-annual Plan Impact Assessments (STECF 2010). However, because the scope and extent of multi-annual management plans has changed considerably following the 2013 CFP reform, the Expert group did not adhere to the format of the guidelines. Nevertheless, the majority of the elements specified in the (STECF 2010) guidelines have been addressed in this report.

As a result of the changes arising through the 2013 CFP reform, the Expert group considers that the STECF (2010) guidelines for impact assessment reporting are in need of revision and suggests that the Commission consider how best this might be achieved. For example, the guidelines required that the STECF organized one or more meetings to define the scope of the proposal. This responsibility relies now in DGMARE, which has to communicate to STECF the scope of the regulation. Based on this information STECF EWGs have to design the simulation exercise.

4 METHODS AND DATA

4.1 Addressing the ToRs

Following the best practices in the field of scientific policy advice the evaluation of the regulation proposal was carried out using simulation testing. For the purpose of this report recent development in the modelling tools for fisheries management, produced under the projects SOCIOEC and MYFISH have been used.

The ToRs set a number of questions that were not possible to approach using a single comprehensive model to run all the simulations required. The settings are quite complex and the forecasts require strong assumptions to be made, in particular due to the introduction of the last revision of the CFP and the effects the landings obligations will have on the fleets' behavior.

On the other hand the removal of HCRs from the MAP legislation, introduced an extra level of complexity to be simulated, which was new for the current model frameworks and techniques.

The new framework for MAPs requires a shift in the analysis concepts, from a situation where scientists were required to assist policy makers designing a MAP, in the sense of studying the trade-offs of candidate HCRs, to a situation where scientists are required to evaluate and give advice on the added value of implementing a MAP when compared with a baseline.

To deal with this new framework a new approach had to be developed in a very short time frame.

The EWG used several models available and defined the scenarios in forms that were expected to provide the necessary information to support the advice. The time frame available was very limited, which conditioned the possibility to test different options to implement the scenarios in each model.

Due to the differences in models and implementation of scenarios, the analyses were carried out in relative terms, comparing the outcomes of specific scenarios to the baseline scenario for each model. Such an approach aims to ensure that the results from each model can be used to evaluate the changes induced by the different scenarios while minimizing the model effect.

The ToR c) and d) where not based on scenario testing due to the complexity of the subjects and lack of time to set up a proper simulation study. As far as possible, the conclusions are based on the quantitative analyses undertaken for ToR a) and b).

4.2 Multi-model approach

The scope of the MAP relates to all demersal fisheries and stocks in the North Sea, Kategatt, Skagerrak and Eastern Channel and hence was too wide to be addressed by the models that currently exist. The approach taken by the EWG was to invite the scientists involved in modeling these areas to contribute to the evaluation. As a result four models were available; an Ecopath with Ecosim (EwE), Fcube, Simfish and Fishrent. A summary of the scope and main concepts of these models is presented in Table 4.1.

These models implement very distinct concepts of the marine system: EwE is a full ecosystem model (NB: a non-spatial version applied here) which accounts for the food-web interactions among species and includes on top a mixed fisheries model with economic information; FCube is a mixed fisheries simulation model with a focus on technical interactions; Simfish is a spatial bio-economic model that within the constraints of different management options, optimizes the effort allocation across fleets to get the maximum economic rent: and Fishrent is similar to Simfish without the spatial component.

Table 4.1 - Overview of the models used for the NS management plans ex-ante evaluation

North Sea models for ex-ante evaluation	FCube	Fishrent	SIMFISH	EwE
Fishery description				
Multispecies (M) / Single species (S)	M	M	M	M
Seasonal		Y		Y
Vessels LoA group				
< 12 m (small scale fishery)	Y			Y
12-24 m	Y		Y	Y
24-40	Y	Y	Y	Y
>40 (long distance fishery)	Y	Y	Y	Y
Type of gear used				
passive	Y			Y
active	Y	Y	Y	Y
polyvavent	Y			Y
Fleets disagreggation Level				
Economic fleet segments	Y	Y	Y	Y
Metier 4 (gear type)	Y			Y
Model characteristics				
Optimisation		Y	Y	Y
Simulation	Y	Y	Y	Y
MSE	Y		HCR	Y
MSE - full feedback loop with stock assessment model				Y
MSE - implementation error				Y
Time step	year	year	year	month
Spatial (Y/N) in case of Y resolution (…)			Y (ICES rect)	
Spatial coverage (North Sea, Skagerrak (Sk), Eastern Channel (EC))	NS+Sk+EC	NS & Sk	NS	NS
Population dynamics	Y		Y	
Biological structure	Y	Y	Y	Y
age (A)	Y	Y	Y	
size (S)				
biomass (B)	Y	Y	Y	Y
Processes: dynamic recruitment (Drec), growth (Gr), Migration (Mig)	Drec.	Drec, Gr	Drec, Gr	Drec, Gr
Simulate recruitment failure (Y/N)		Y	Y	Y
Fleet dynamics				
based on F (F) / effort (E)	E, F	F,E	E	E, F
selectivity (model or fixed)	Fixed	Fixed	Fixed	Fixed
Economic dynamics				
Price elasticity			Y	
Costs	Y	Y	Y	Y
Employment or FTE		Crew cost	crew costs	partially
Fuel costs	Y	Y	Y	implicit only
MANAGEMENT OPTIONS (Yes/No/Development)				
De minimis	Y	Y	Y	Y
Interspecies quota flexibility				
Swaps			Y	
Borrow and banking				
ICES data limited stocks				Y
F target	Y	Y	Y	Y
TAC & quotas	Y	Y	Y	Y
Biomass safeguards	Y	Y	Y	Y
Combined TACs (multiple species in one TAC)				
Diferenciated management between driver and non-driver stocks	Y			Y
Multidimentional Fmsy ranges	Y			
Harvest control rules	Y	Y	Y	Y
Temporary closure of fishery		Y	Y	Y
Area closures			Y	Y
INDICATORS (Yes/No/Development)				
Impact on biodiversity				Y
Abundance of main stocks	Y	Y	Y	Y
Evolution of main predator and prey stock			Y	Y
Profitability		Y	Y	Y
Income	Y	Y	Y	Y
Supply	Y	Y	Y	Y
Fuel consumption		Y	Y	
Employment		Y	Y	Y
Compliance				
Stocks				
Cod (COD)	Y	Y		Y
Haddock (HAD)	Y			Y
Whiting (WHG)	Y			Y
Saithe (POK)	Y	Y		Y
Sole (SOL)	Y		Y	Y
European place (PLE) IV & VIId	Y		Y	Y
Nethrops	Y			Y
Turbot (TUR)	Y			Y
Shrimp			Y	Y
Others				Y

Annexes I-IV present detailed descriptions of each of the models and the results that were considered pertinent to the scenarios investigated.

Each model was used to address specific questions and provide information on different sets of the indicators requested by the Commission. In many cases the indicator values were expressed relative to the baseline scenario. In this way the Expert Group aimed to minimize model effects and permit a comparison of between-model results.

Due to the characteristics of the models and the starting point of the forecasts (EwE starts in 2008 while the other models in 2016), model outputs were used to evaluate distinct perspectives of the forecast. The EwE model was used to evaluate long-term effects (30 years) while the other models results were used to evaluate short-term effects and provide a snapshot of the potential status in 2020.

4.3 Scenarios

Two sets of scenarios were investigated, the management scenarios and the fleet scenarios. The first relates to the decision making options that were simulated to evaluate the trade-offs across options and inform decision makers of the effects/impacts that their decisions may have. The fleet scenarios aimed to inform on the likely responses from the fleets to the decisions taken. Such scenarios are the most difficult to forecast, as the reactions of the sector can vary widely and unexpectedly. Hence, the fleet scenarios are inevitably based on strong assumptions about likely responses, which may or may not be entirely accurate.

4.3.1 Management scenarios

The management scenarios were designed to evaluate whether a MAP with the characteristics proposed by DGMARE (see background), would be more successful at achieving the objectives set by Artº 2 of the CFP than simply implementing the basic CFP provisions.

Not all details of the MAP were implemented as some components were not possible to simulate, e.g. technical measures or other potential management options that are to be set by regional bodies and are currently unknown.

Implementation of the basic CFP provisions constituted the baseline scenario and was implemented by considering the following:

- management through TACs/quotas;
- perfect implementation of the landings obligations (no discards);
- MSY targets;
- time frame to achieve the MSY targets 2015-2020;

Compared to the baseline scenario, through Art.9 extended by the task force agreement (Anon. 2014), the MAP framework provides for the following additional components:

- using F_{MSY} ranges instead of single values;
- biomass safeguards and remedial actions to recover the stock should SSB fall below B_{pa};

The new MAP framework does not include HCRs, meaning that the Council has the freedom to decide on how it wishes to fix fishing opportunities and achieve the objectives of the CFP. The EWG was therefore faced with the problem of how to evaluate the provisions of the MAP in the absence of an HCR to derive a target fishing mortality rate. The EWG decided that the best alternative would be to use an "envelope" approach. Such an approach considered the potential consequences of fishing at the extremes (upper and lower) of the F_{MSY} ranges, to simulate both high and low exploitation cases, and thereby inform managers on the range of potential outcomes of alternative tactical management decisions, without giving advice about the 'best' way to get to the target.

Note that in this approach each scenario has two management options that lead to two simulations:

- upp – TAC_{Y+1} is set as the catch that results from exploiting the stock at $FMSY^{upp}$
- low - TAC_{Y+1} is set as the catch that results from exploiting the stock at $FMSY^{low}$

where $FMSY^{upp}$ and $FMSY^{low}$ are the upper and lower limits of the FMSY range respectively.

In both cases the biomass safeguards were set at the precautionary biomass (Bpa). In the absence of an HCR to define the tactics to recover the stock, the recovery period was simulated by reducing F linearly for the time to rebuild the SSB. There were two recovery periods simulated, 5 and 10 years, as requested by the ToR. Due to distinct ways of implementing management options the safeguards were implemented slightly differently across models (see Annexes I-IV for details).

4.3.2 Fleet scenarios

The likely responses of the fishing sector to any management decisions are of major importance when forecasting potential stock and fleet impacts. The range of potential responses is very wide, which makes it extremely difficult to forecast. Consequently, the approach taken was to devise a set of plausible assumptions that allow the evaluation of the impact on the outcomes of such assumptions. Such an approach does not constitute a full sensitivity analysis, but it does provide information about the robustness of the conclusions.

A further major assumption relates to the implementation of the LO, which is probably the most important factor likely to influence future fleet behaviour and the least predictable. Although various options of how to simulate incomplete or no implementation of the LO were discussed, the Expert Group concluded that the only reasonable assumption to make was that if the LO will be perfectly implemented. Nevertheless, it was not possible to simulate the potential effects of the different flexibility mechanisms such as inter-species flexibility, *de minimis* exemptions, exemptions based on high survival, swaps or banking and borrowing.

There are two main interpretations of the LO implementation:

1. the first considers that the current discard practices will be mitigated through changes in gear selectivity and fleet behavior, resulting in a reduction in fishing mortality;
2. the second considers that the flexibility mechanisms introduced will allow the fleet to keep fishing as before, but will require a more complex balancing of the quotas at the end of the year.

These interpretations will be reflected in the fleet's behavior by not having the possibility to over catch the quota, the first option, or by allowing the fleets to over catch their quota, which is allowed in the second option.

There were two scenarios implemented for the fleets' behavior:

- lowest quota – the fleet stops fishing when the lowest quota is exhausted leaving part of the fishing opportunities unused;
- maximum economics – the fleet operates to maximize its profits, over-fishing some of the quotas, also leaving part of the fishing opportunities unused but not as much as in the “lowest quota” case.

The implementation of these scenarios was not equal across all models. For details check Annexes I-IV.

Note that the lowest quota scenario is more-closely related to the first interpretation of the LO implementation while the maximum economics scenario is more closely related to the second interpretation.

4.3.3 Scenario summary

In summary, 2 fleet scenarios and 4 management scenarios were investigated. Implementation of the provisions of the MAP comprised 2 options to perform the envelope analysis. The table below summarizes each scenario and how they were used to address the ToRs.

Table 4.2. Summary of scenarios analyzed

Management scenario				**Fleet scenario**	
name	**runs**	**description**		**Lowest quota**	**Maximum economics**
CFP	cfp	Target:	Fmsy	ToR a)	
		Time to target:	2016		
CFP2020	cfp2020	Target:	Fmsy	ToR a)	
		Time to target:	2020		
MAP fast recovery	map.low	Target:	lower limit of Fmsy range	ToR a) and b)	
		Time to target:	2016		
		Safeguards:	Bpa		
		Recovery period:	5 years		
	map.upp	Target:	upper limit of Fmsy range		
		Time to target:	2016		
		Safeguards:	Bpa		
		Recovery period:	5 years		
MAP slow recovery	map10y.low	Target:	lower limit of Fmsy range	ToR b)	
		Time to target:	2016		
		Safeguards:	Bpa		
		Recovery period:	10 years		
	map10y.upp	Target:	upper limit of Fmsy range		
		Time to target:	2016		
		Safeguards:	Bpa		
		Recovery period:	10 years		

4.4 Data

A summary of the data and parameters used to tune and condition the models is presented in Table 4.3. For more details check the model annexes (Annexes I-IV).

Table 4.3. Summary of data and parameters used

	EwE	FCube	Simfish	Fishrent
Population dynamics	ICES 2008	ICES 2014	ICES 2012	ICES 2014
Trophic interactions	ICES 1991 Year of the Stomach and others			
Fleet exploitation	ICES 2008	ICES 2014	ICES 2012	ICES 2014
Fleet economics	STECF AER 2012	STECF AER 2014 modeled (see annex V)	STECF AER 2013	STECF AER 2014
Fleet interactions	STECF Effort DB 2012	ICES data call for WGMIXFISH 2014	Data from national institutes (LEI, TI & CEFAS) as of 2010	STECF AER 2014
Fmsy	ICES WKMSYREF3 (2014) updated during the meeting to conform ADG	ICES WKMSYREF3 (2014) updated during the meeting to conform ADG	ICES WKMSYREF3 (2014) updated during the meeting to conform ADG	ICES WKMSYREF3 (2014) updated during the meeting to conform ADG
Bpa	ICES 2014	ICES 2014	ICES 2014	ICES 2014
Employment	STECF AER 2014			

Processing of model outputs for final analysis and visualization was conducted using the FLR packages (Kell et al, 2007; http://flr-project.org) for the R language (R Core Team, 2015) version 3.1. These toolset is also employed by the software implementing the FCube method.

5 TOR A)

[*What are the consequences of achieving, by 2016 and by 2020, fishing mortalities within the F_{MSY} ranges provided by ICES, with particular emphasis on the stocks of cod, haddock, whiting, saithe, sole, plaice and Nephrops?*]

The trade-offs across management options were evaluated through simulation testing. The results of the analysis were very extensive and were summarized in a set of plots that reflect the impacts in the stocks and fleets, in the short term (2016-2019), in 2020 and in the long term (25-30 years). For each period a different set of results was used depending on the model results available.

5.1 Short term effects

Figure 5.1 and Figure 5.2 show the short term effects on the stocks for the maximum economics and the lowest quota scenarios, respectively.

For both scenarios, the differences between the baseline and the CFP2020 scenario are minor. With regards to the MAP scenario, fishing at the upper limit of the F_{MSY} range will generate larger catches for all stocks with the trade-offs of higher inter-annual variability, larger fishing mortalities which can be 50% above the baseline, and lower biomasses than the baseline, increasing risks to B_{lim} for cod and B_{pa} for haddock and sole. In this case of fishing at the lower range, the catches are lower and show lower inter-annual variability, leaving higher biomasses and reducing the risks to B_{lim} and B_{pa}. The largest trade-off to fishing at the upper limit is keeping biomasses at lower levels. Such that the large increase required in fishing mortality, when compared to the baseline, may not be balanced out by CPUE, leading to a less profitable fishery.

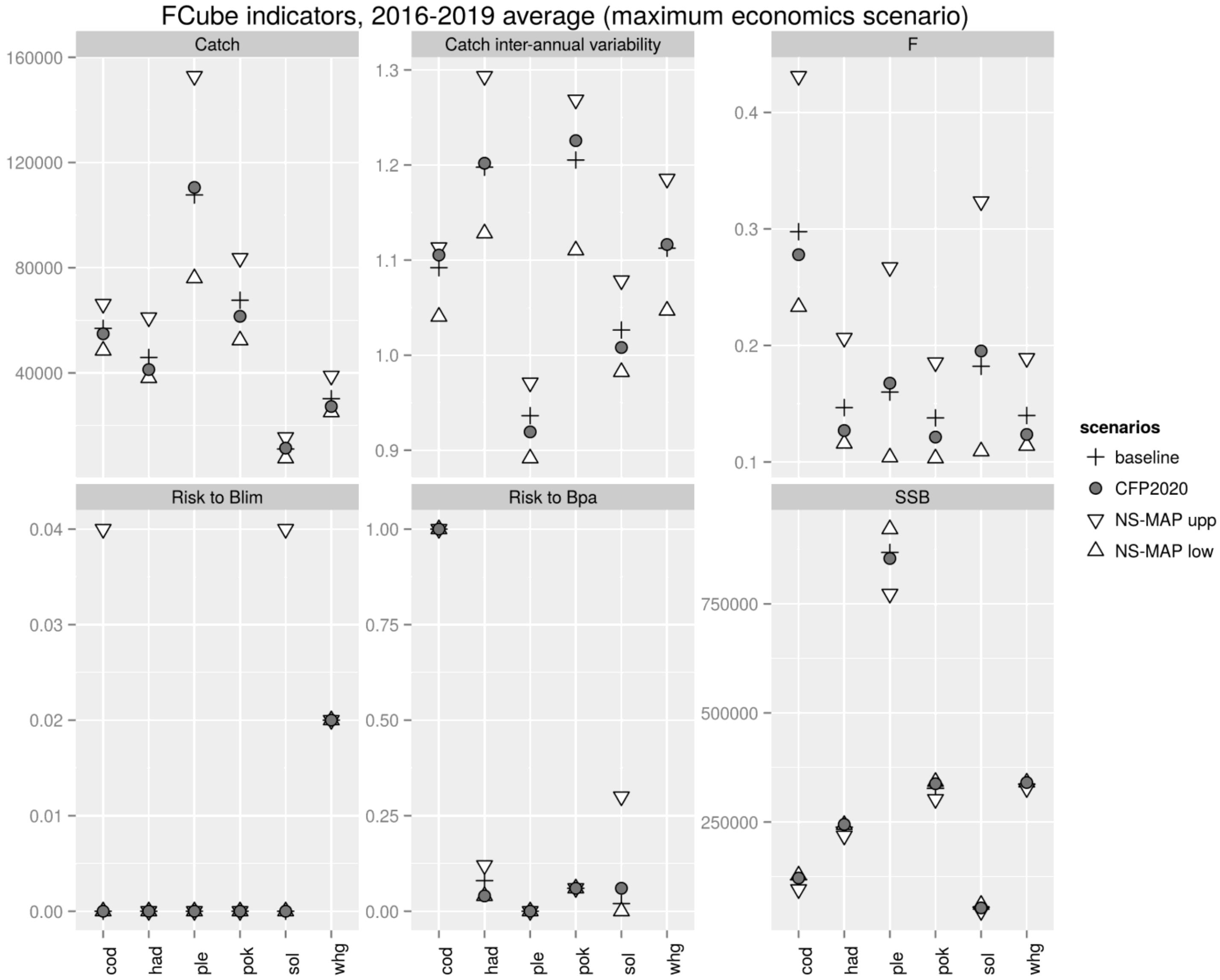


Figure 5.1 - Stock indicators for the maximum economics scenario in the short term.

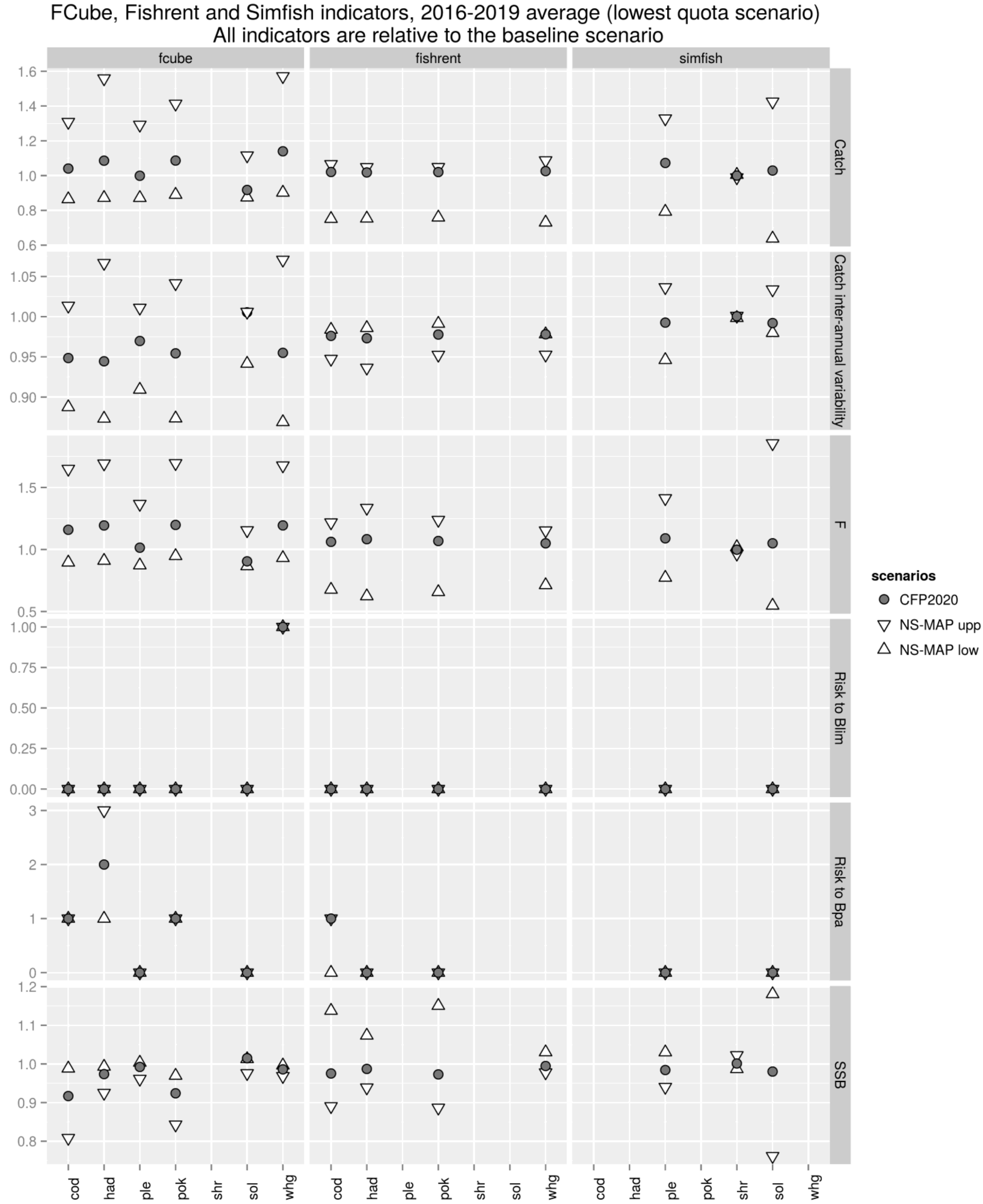


Figure 5.2 - Stock indicators for the lowest quota scenario in the short term.

Figure 5.3, Figure 5.4 and Figure 5.5 show the short term effects on the fleets for the maximum economics and the lowest quota scenarios by FCube, Simfish and Fishrent, respectively. Note that FCube uses a combination of the metier definition and vessel size to approximate the economic fleet segments, while Simfish and Fishrent use the economic fleet definition. These two definitions can lead to substantially different allocation of vessels to fleets and computation of effort, in particular for the vessels that can distribute their effort to several gears throughout the year. The economic definition will allocate all the operation of those vessels to the most used gear each year, while the metier definition will split the effort across each gear, duplicating when several gears are used simultaneously.

The CFP2020 scenario is not very different from the baseline scenario. Fishing at the upper limit of the F_{MSY} range provides the same or more landings than the baseline scenario, but requires more effort to be deployed for most fleets, which may have a negative impact on profitability. Fishing at the lower limit of the FMSY range inverts these results.

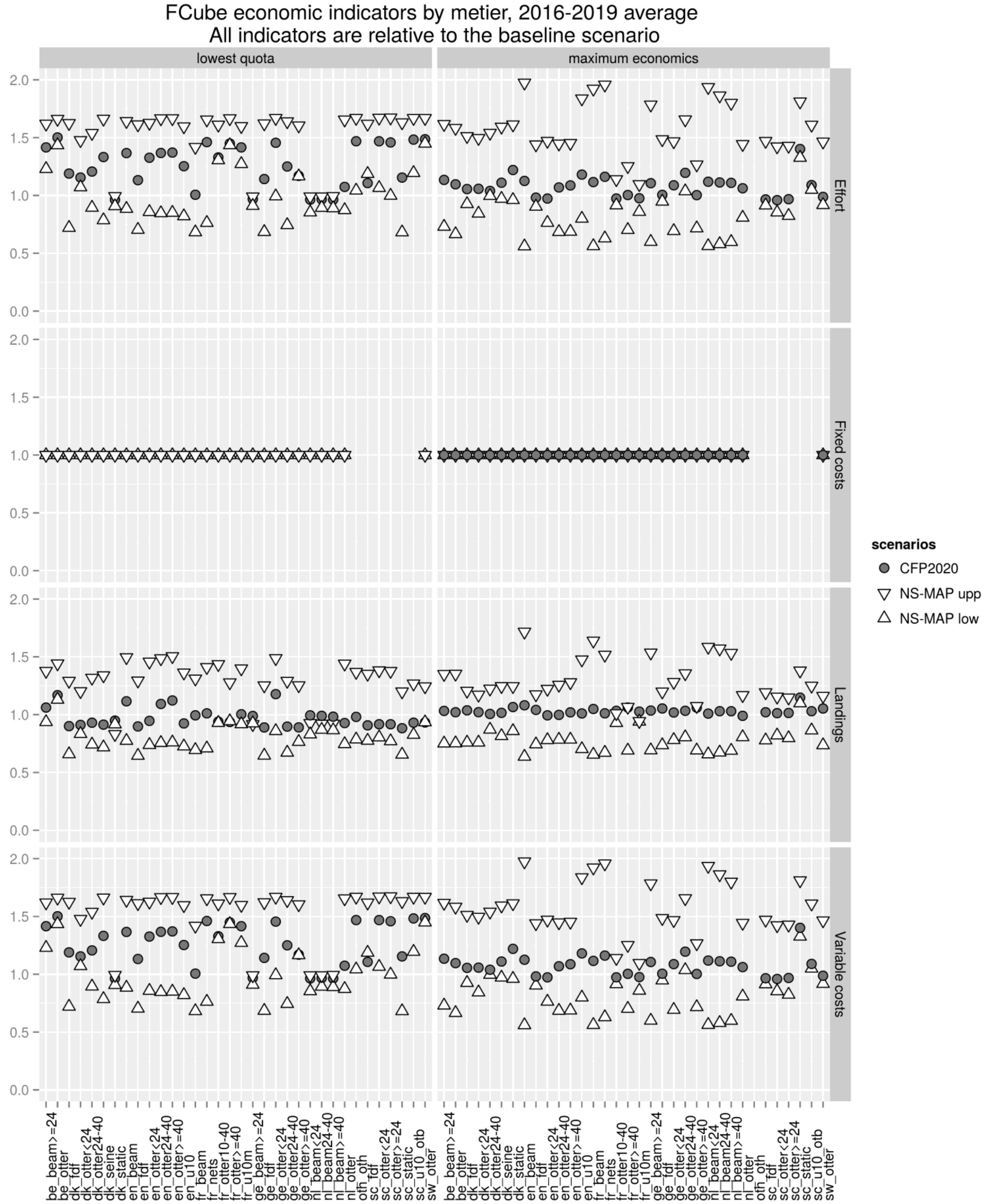


Figure 5.3 - Fleet indicators in the short term by FCube.

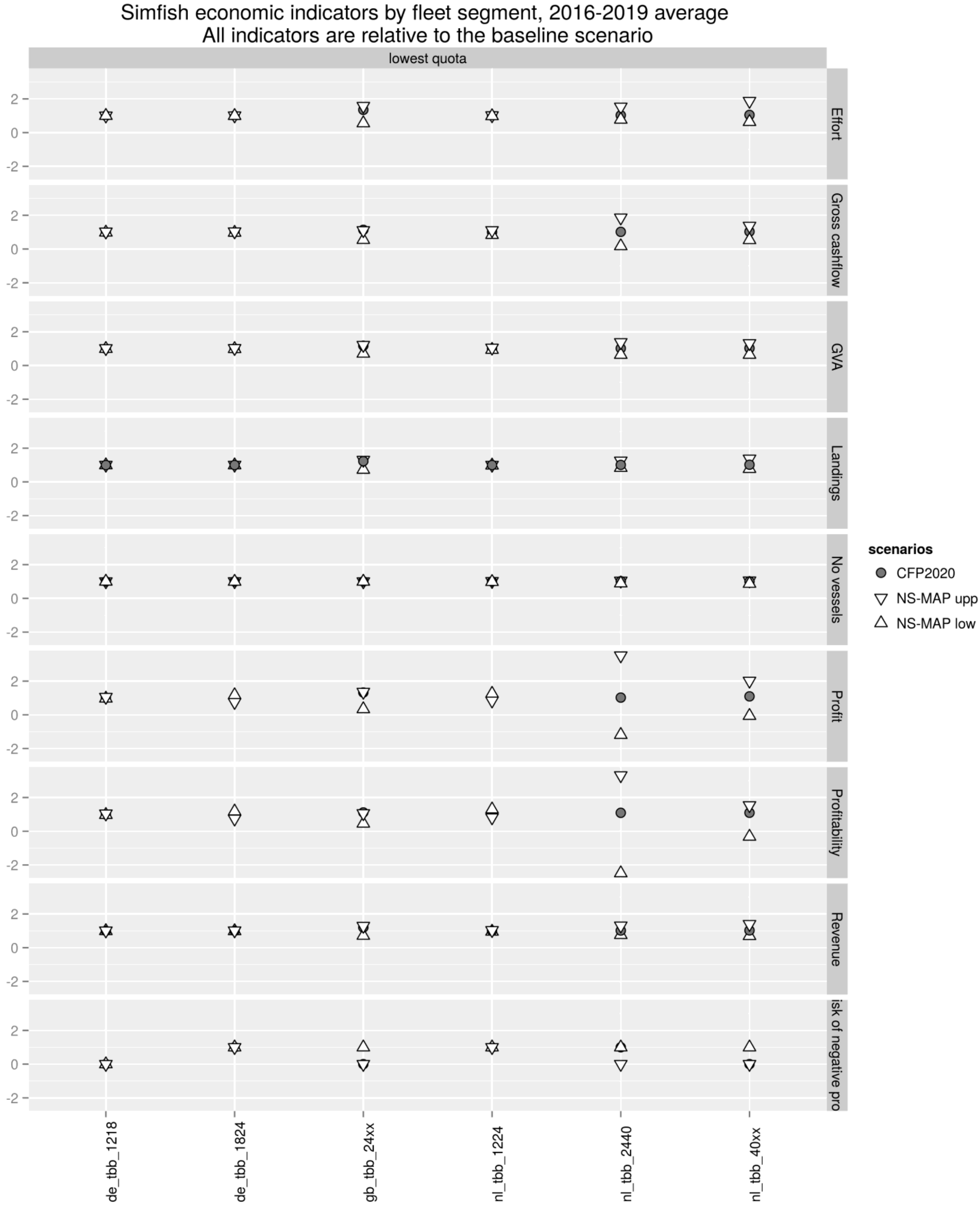


Figure 5.4 - Fleet indicators in the short term by Simfish.

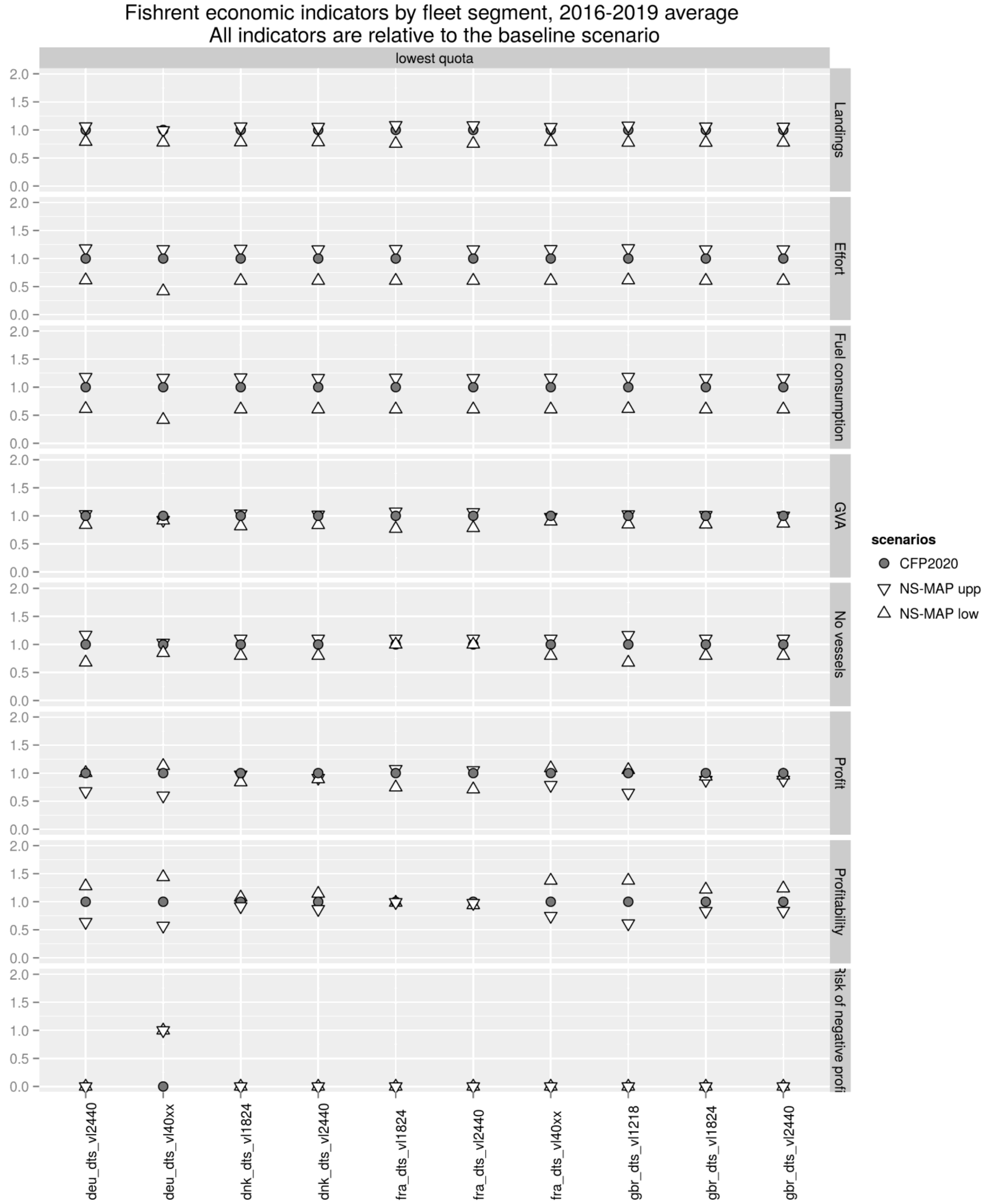


Figure 5.5 - Fleet indicators in the short term by Fishrent.

5.2 Effects in 2020

Figure 5.6 and Figure 5.7 show the effects in 2020 on the stocks for the maximum economics and the lowest quota scenarios, respectively.

In 2020 the baseline and the CFP2020 scenario have the same exploitation target, which results in similar fishing mortalities.

For all management scenarios, catches are lower but not too different from the short term. The snapshot shows that SSB is higher than the average period 2016-2019, which is reflected in lower risks to B_{pa} and B_{lim}, with the exception of cod and sole's risk to B_{lim}. In the case of fishing at the upper level of the F_{MSY} range the stocks of cod and sole show a potential increased risk to B_{lim} in 2020 when compared with the average of the period 2016-2019.

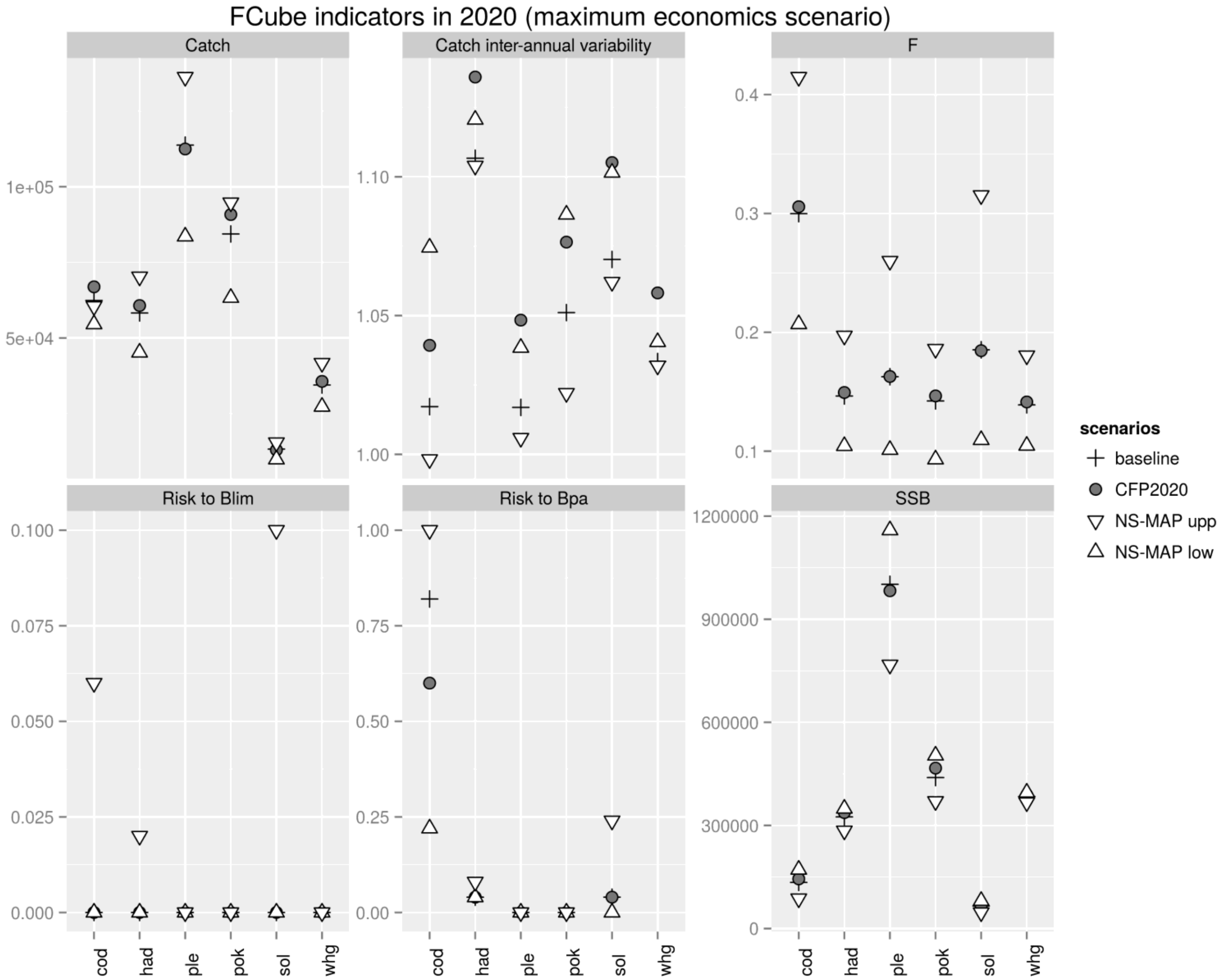


Figure 5.6 - Stock indicators for the maximum economics scenario in 2020.

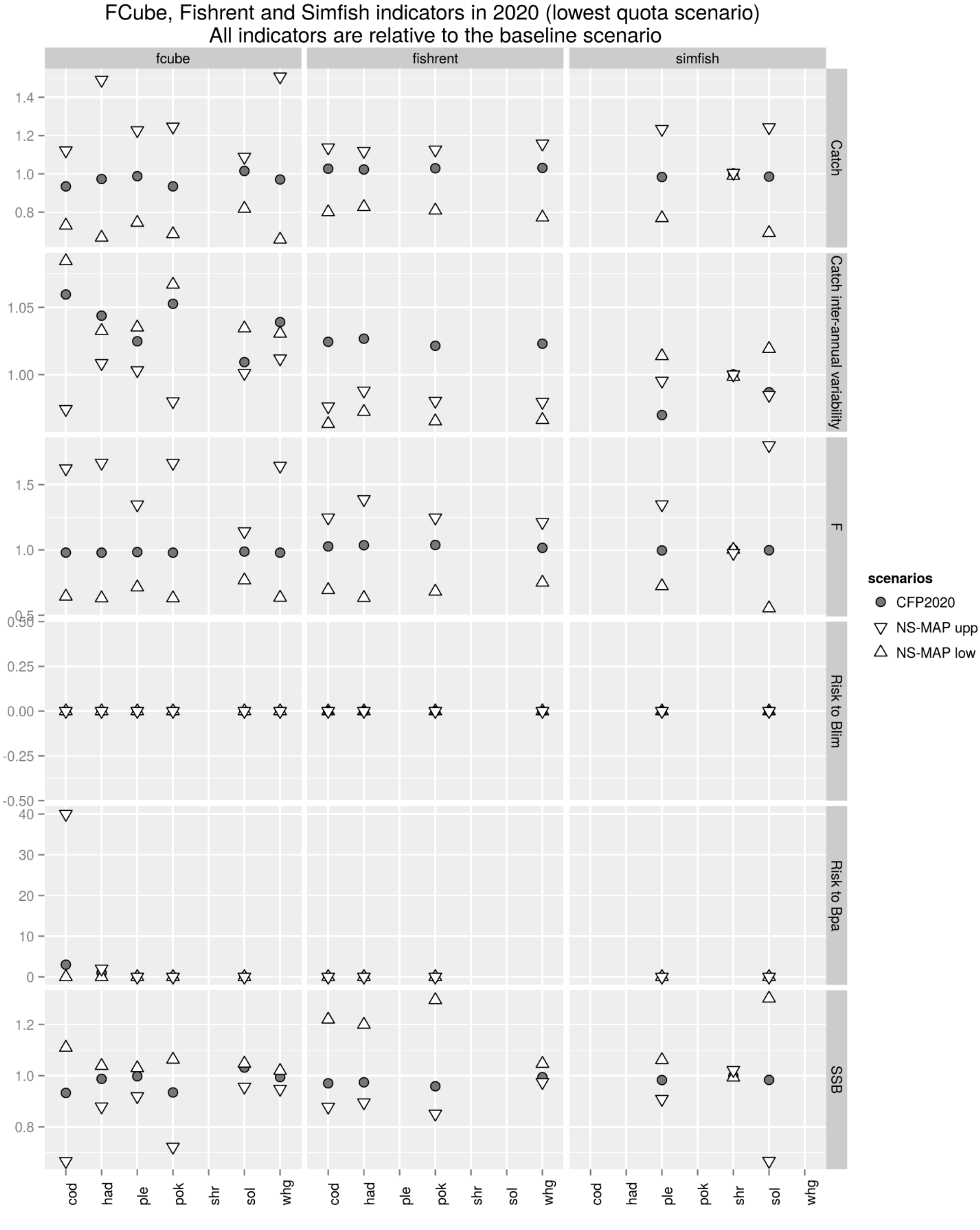


Figure 5.7 - Stock indicators for the lowest quota scenario in 2020.

Figure 5.8, Figure 5.9 and Figure 5.10 show the effects in 2020 on the fleets for the maximum economics and the lowest quota scenarios by FCube, Simfish and Fishrent, respectively. Note that FCube uses the metier definition for fleets, while Simfish and Fishrent use the economic fleet definition. These two definitions can lead to substantially different allocation of vessels to fleets and computation of effort, in particular for the vessels that can distribute their effort to several gears throughout the year The economic definition will allocate all the operation of those vessels to the most used gear each year, while the metier definition will split the effort across each gear, duplicating when several gears are used simultaneously.

In general the results are more stable than the average 2016-2019, which reflect the constant dynamics on prices and costs that these models have. The economic performance becomes more dependent on the assumptions made regarding these dynamics, mainly scaling the effort and catches as costs and revenues.

The general perspective shows that the management scenario CFP2020 is very similar to the baseline, as expected since the management targets are the same at this point in time. The MAP scenarios show that exploiting the stocks at the upper level of the F_{MSY} range will result in larger landings but with higher costs, which may not be balanced out by the catch increase resulting in potential decreases in profits.

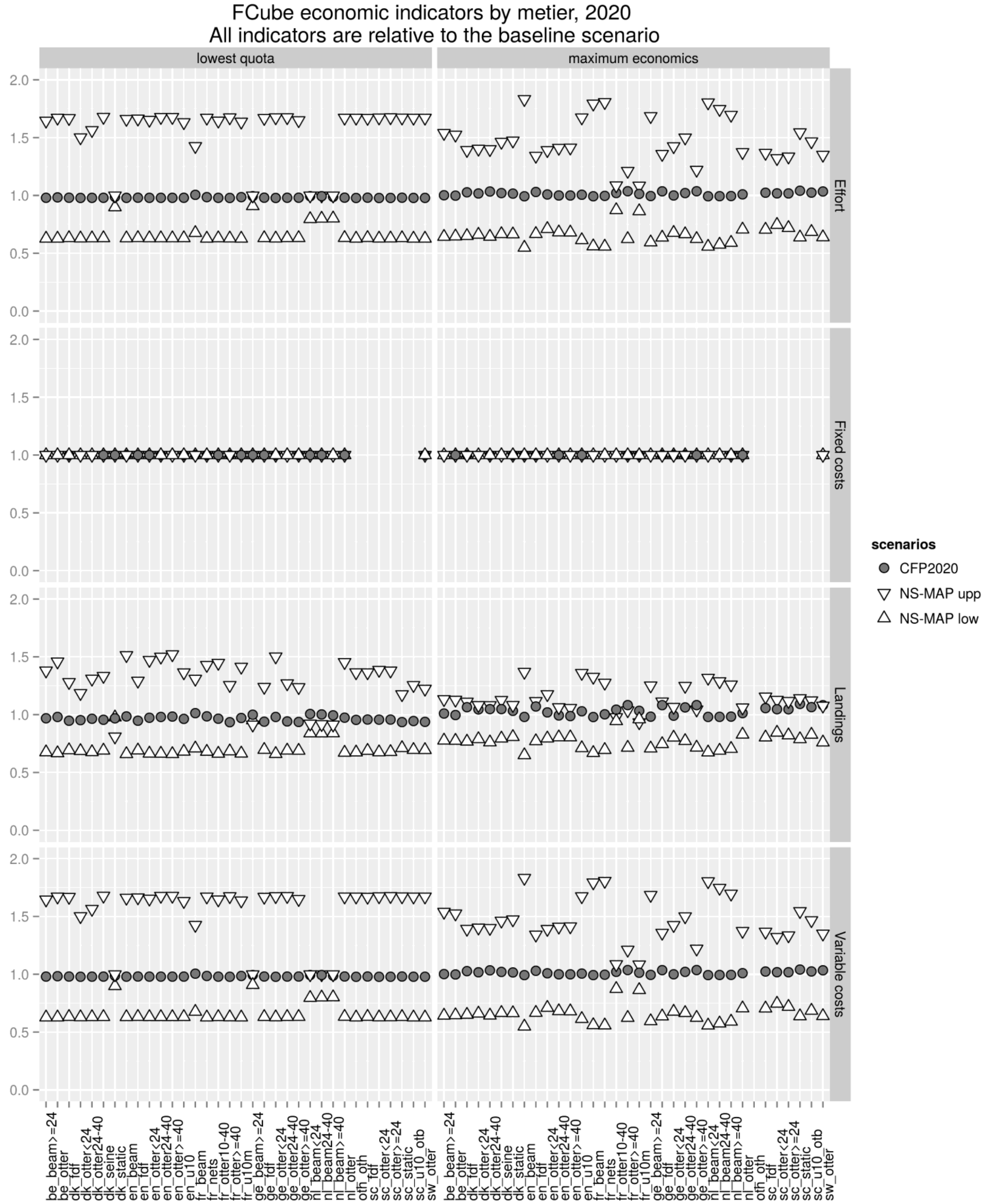


Figure 5.8 - Fleet indicators in 2020 by FCube.

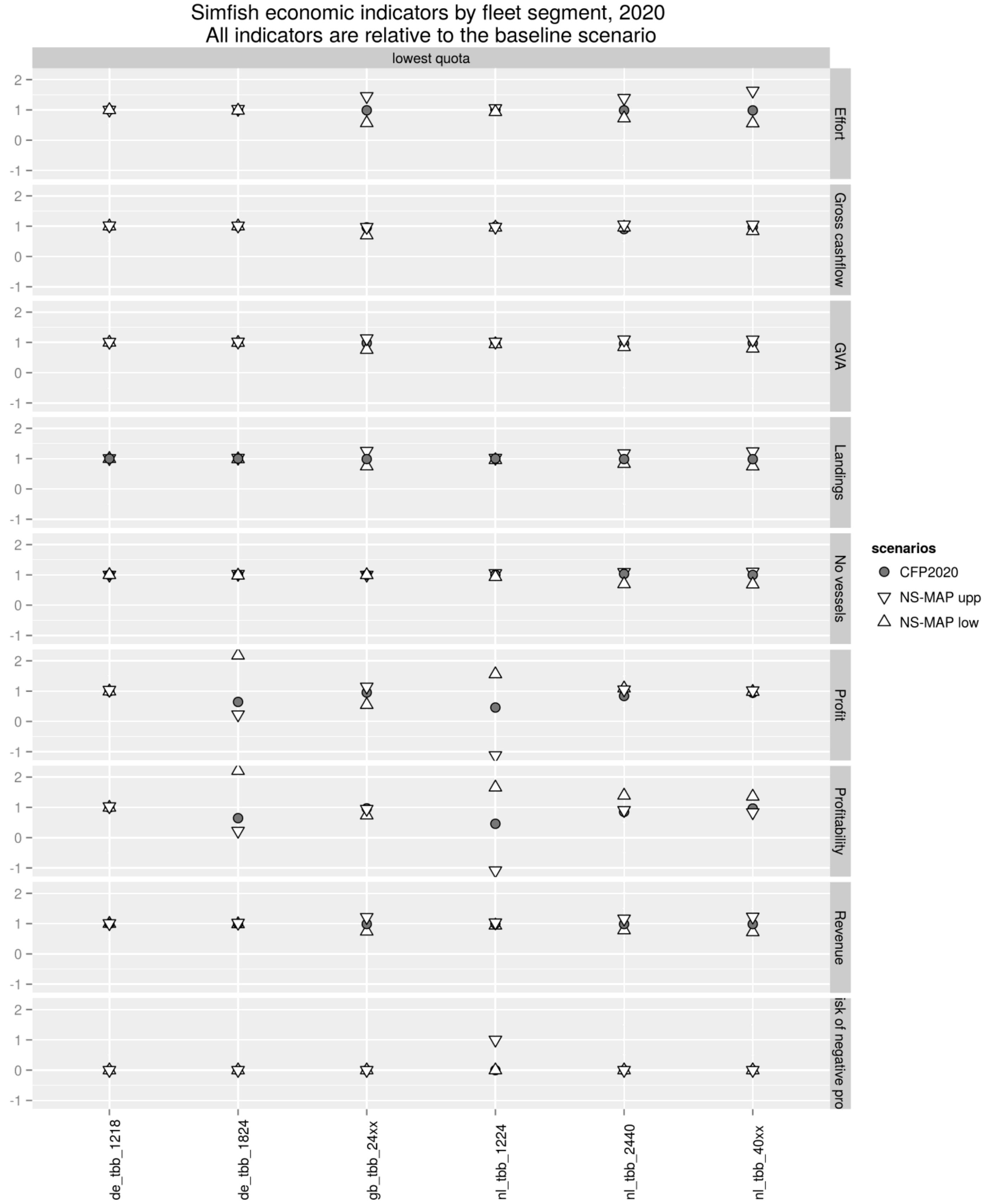


Figure 5.9 - Fleet indicators in 2020 by Simfish.

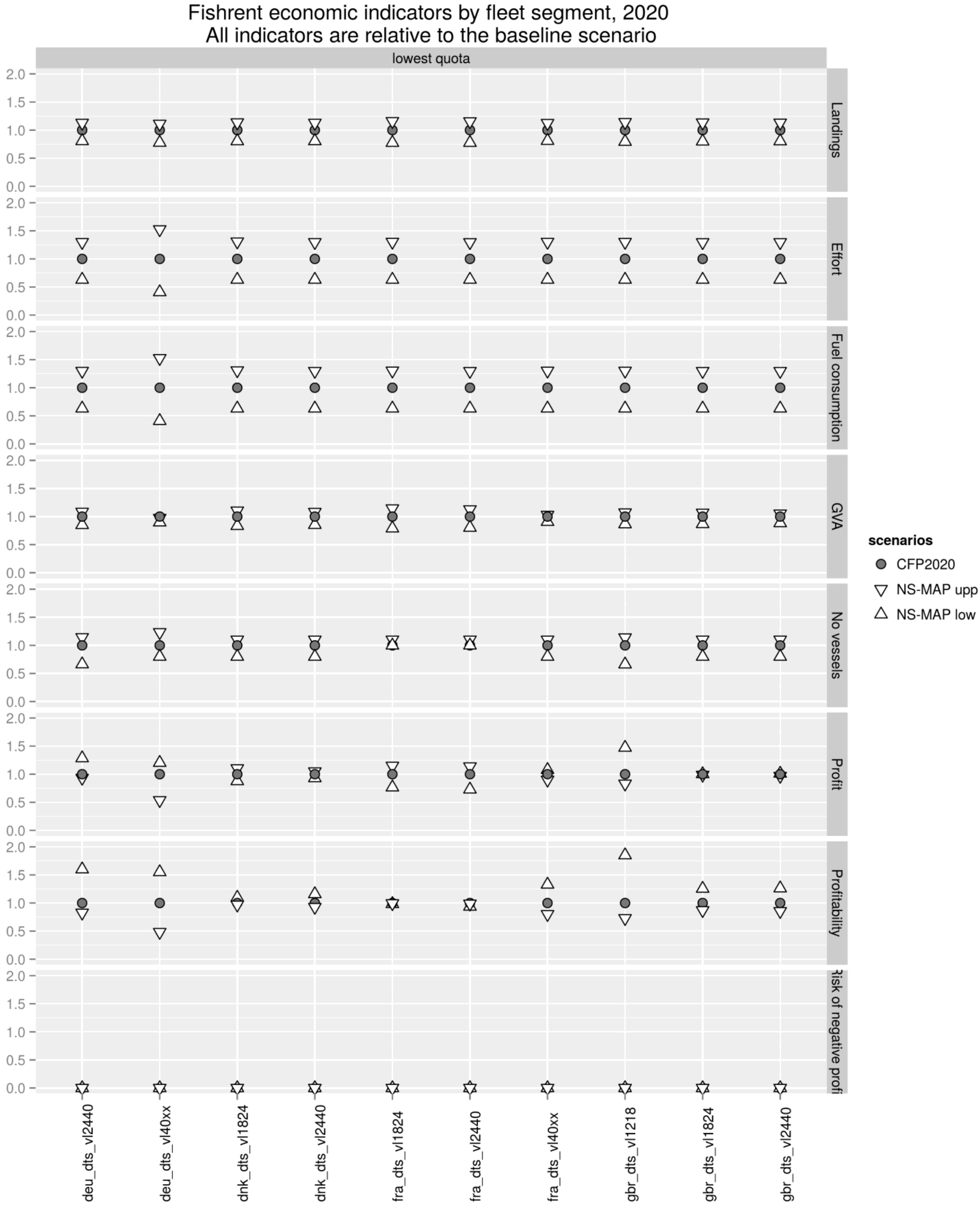


Figure 5.10 - Fleet indicators in 2020 by Fishrent.

5.3 Long term effects

Long term effects were evaluated as the indicators' average of the last 5 years of a 30 years forecast with EwE. Effects on the stocks are shown in Figure 5.11 and Figure 5.12, for the fleet scenarios maximum economics and lowest quota, respectively. Effects on the fleets are presented in Figure 5.13. EwE uses the economic fleet definition (see sections above for a detailed explanation).

In the long term, fishing at the upper level of the F_{MSY} range generates larger catches than the baseline, while the lower level produces smaller catches. The trade-offs are between biomass levels (separating some adult and juvenile groups, EwE uses SSB for cod, haddock, whiting, saithe and herring and total biomass for all other groups) and the fishing mortality required to get those catches, which can be seen as a proxy for variable costs. Fishing at the upper limit of the Fmsy range generates more catches but keeps biomass at lower levels, which implies an increase in biological risk and an increase in effort.

As expected the inter-annual variability is not so important when compared with short term periods, the stocks and fisheries should be close to equilibrium at this point.

The figures also show a large increase in the risk to B_{lim}, although these values have to be analysed with care. The probability of falling below Blim tends to be small, hence a small change in absolute terms can represent a very large change in the probability ratios.

Considering the species of focus in this evaluation, a notable result from the EwE model is that Nephrops biomass benefit from the scenarios that lead to higher fishing rates on its predators. It shows how by taking species interactions in to account, ecological and fishery trade-offs are revealed.

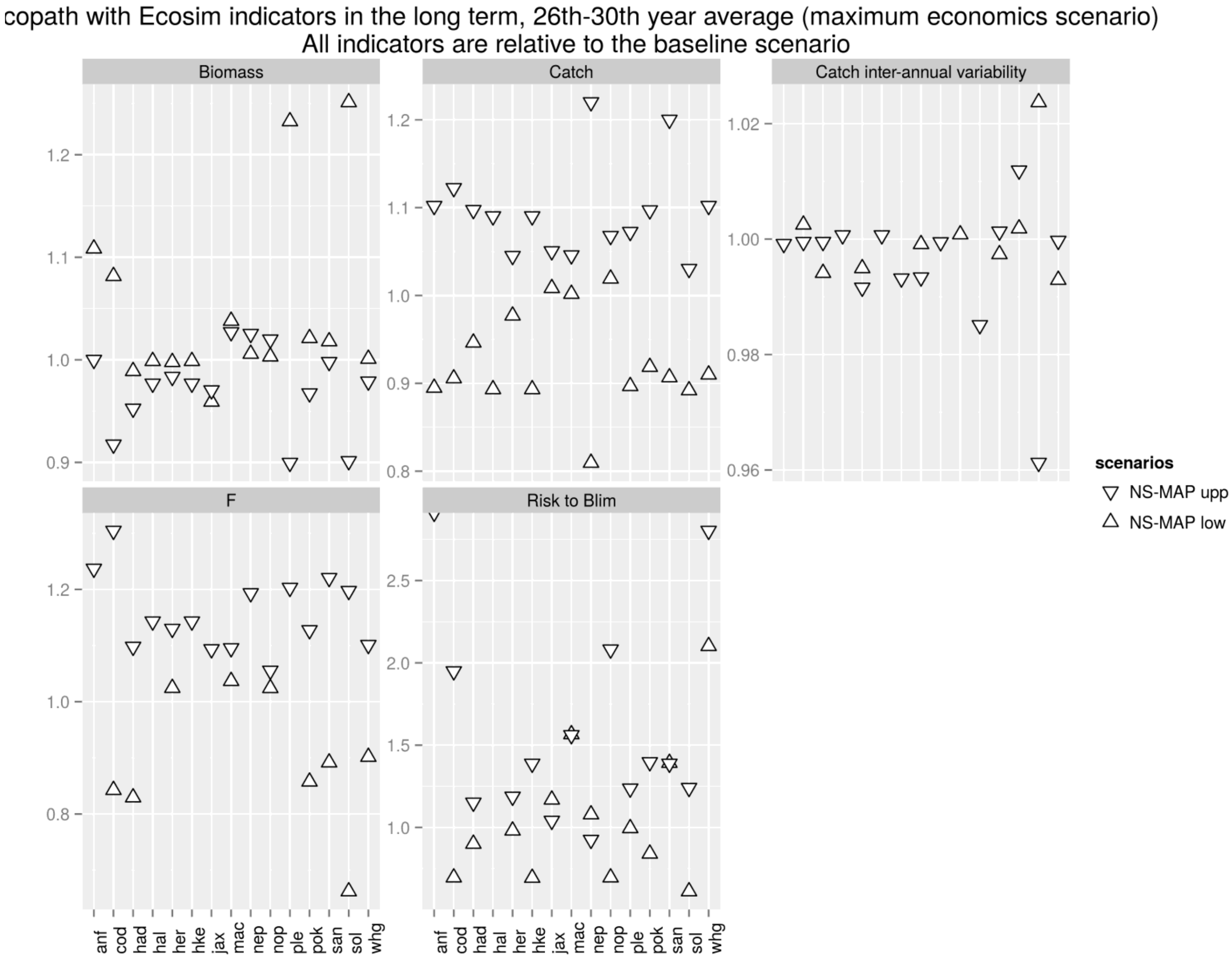


Figure 5.11 - Stock indicators for the maximum economics scenario in the long term.

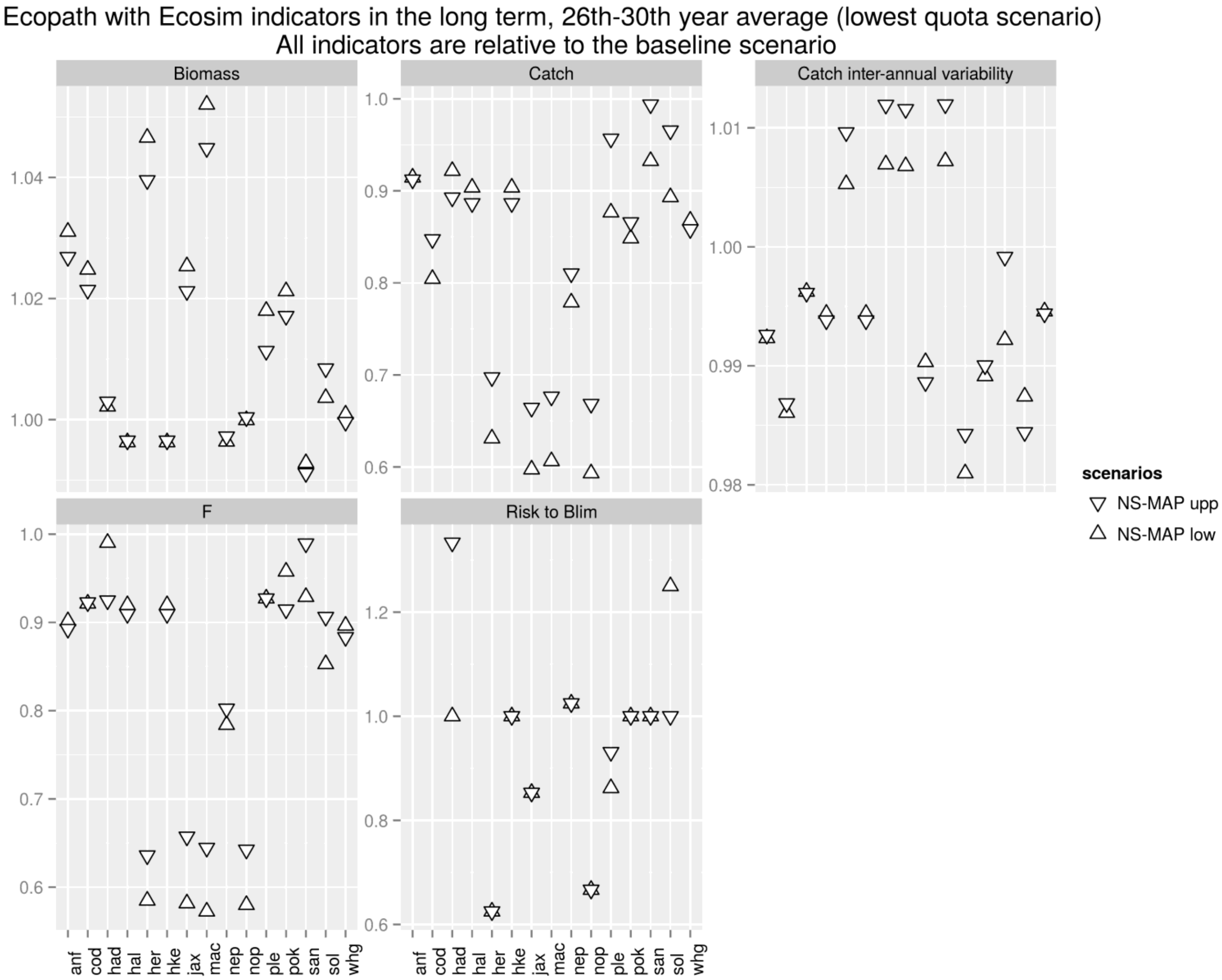


Figure 5.12 - Stock indicators for the lowest quota scenario in the long term.

Fleets' performance in the long term is difficult to forecast, as such these results must be considered somewhat speculative as the dynamics on prices and costs as well as catchabilities, are fixed. Nevertheless, the results show some important information.

The lowest quota scenario produces catches which are lower than the baseline catches resulting in lower revenues, although fishing effort is kept more or less at the same level, which may have a negative impact on profitability (see notes in annex II for details on the model behavior in lowest quota scenarios).

The maximum economics scenario tries to maximize revenue from catches. In the case of fishing at the upper limit of F_{MSY} ranges, the maximization of revenue requires an increase in effort relative to the baseline. In the case of fishing at the lower limits the revenue is lower than the baseline, but is obtained at lower levels of fishing effort. The impacts on profitability are not possible to assess for the long term.

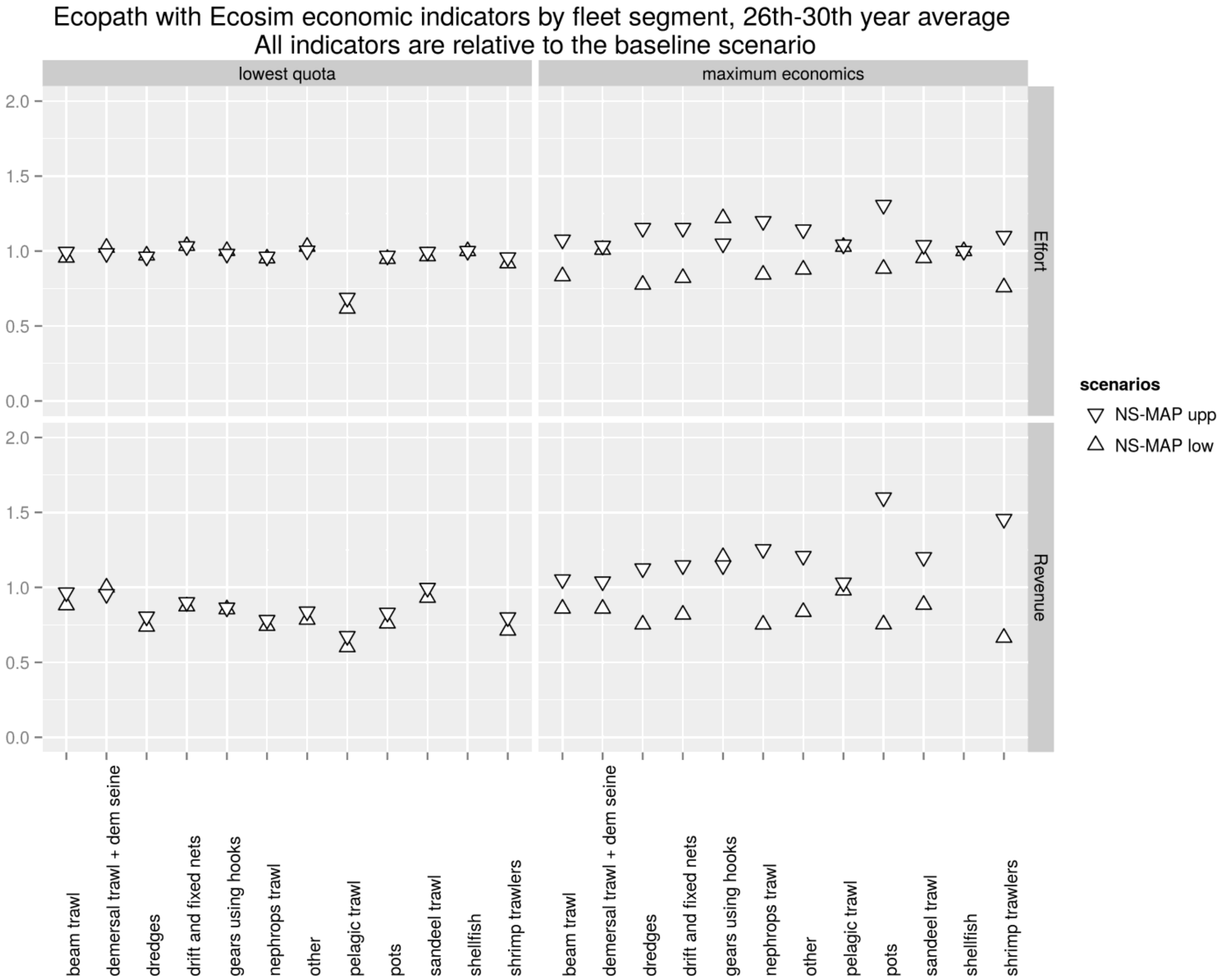


Figure 5.13 - Fleet indicators in the long term.

5.4 Social Indicator – Employment and Dependency on the "Big 6 plus Nephrops" in the North Sea / Area 27

The data used for evaluating employment for EWG 15-02 (EWG MAP) came from DCF data compiled for the STECF Annual Economic Report (2014 AER) regional analysis. 2012 data was chosen to provide consistency with the models being used (FISHRENT and SIMFISH).

Initial discussions gave rise to the view that there was no evidence to support that changes in TAC and expended fishing effort (resulting from a change in Fmsy), would provide direct correlation to changes in employment. Nevertheless, for the purposes of the NS MAP it is useful to have an understanding of the numbers of fishers directly involved in the fisheries in question. Economic dependency on the fisheries under review is also important for understanding how the fleets may be impacted.

5.4.1 Steps Taken

The first step involved taking relevant data from the AER regional analysis, for the fleets in question, including: Employment (both total number employed and full time equivalent (FTE)), landings (value and weight on FAO level) and effort (gear level data). Using these data several indicators, such us economic dependency on the fishing activity in the NS and the "Big 7" (cod, haddock, whiting, plaice, sole, saithe, and nephrops), were calculated.

The final evaluation included total employment for fleets dependent on the Big 7 with selection focused on the value of landings from these species compared with each fleet's overall Area 27 landings' values, in order to estimate fleet dependency on these stocks.

For the purposes of estimating how employment may be impacted by a change in F_{MSY}, an analysis was undertaken to highlight fleets with "high" and "low" employment. Straight employment numbers were then compared with the economic dependency indicator (landings values of the Big 7 compared to the total landings values).

5.4.2 High Employment Fleets

Some of the highest employment can be found with the Under 10m fleets, which would be expected, given the nature of these fleets; 7 of the top 20 fleets, for example are "under 10" fleets (Table 5.1), employing 7753 individuals. The dependency measure, however, indicates low dependency on the Big 7 in the NS for the majority of such fleets.

Table 5.1. Top 11 small scale (<10m) fleets with high employment

AER fleet segments	Employment in the fleet segment (number of employees)	Value of Big 7 in the NS compared to overall value of landings of the fleet
GBR AREA27 FPO VL0010	2846	2%
GBR AREA27 DFN VL0010	1011	29%
GBR AREA27 HOK VL0010	860	3%
GBR AREA27 DTS VL0010	601	40%
GBR AREA27 FPO VL1012	478	0%
FRA AREA27 FPO VL0010°	431	1%
FRA AREA27 DFN VL0010°	427	11%
NLD AREA27 PG VL0010	359	20%
FRA AREA27 HOK VL0010	313	0%
GBR AREA27 PGP VL0010	214	13%
DNK AREA27 PGP VL0010°	213	24%

The larger demersal trawling fleets (DTS and TBB) also have high employment, with the top 11 fleets employing 6433 individuals (Table 5.2). Half of these are GBR and NLD fleets. As summarized below (dependency section), the dependency on the "Big 7" in the NS Area 27 is high for more than half of these fleets.

Table 5.2. Top 11 large fleets with high employment

AER fleet segments	Employment in the fleet segment (number of employees)	Value of Big 7 in the NS compared to overall value of landings of the fleet
GBR AREA27 DTS VL1824	1080	52%
GBR AREA27 DTS VL1218	971	21%
FRA AREA27 DTS VL1824	783	4%
NLD AREA27 TBB VL40XX°	734	67%
FRA AREA27 DTS VL1218	619	2%
NLD AREA27 TBB VL1824°	586	21%

AER fleet segments	Employment in the fleet segment (number of employees)	Value of Big 7 in the NS compared to overall value of landings of the fleet
FRA AREA27 DTS VL2440	423	3%
FRA AREA27 DTS VL1012	391	6%
GBR AREA27 TBB VL2440	304	45%
SWE AREA27 DTS VL2440	293	4%
DNK AREA27 DTS VL1218°	248	59%

5.4.3 Low Employment Fleets

27 fleets employ fewer than 100 individuals. The majority of these fleets are from MS with lower employment/fewer boats such as Belgium (4), Denmark (11), and Germany (5).

The fleets that are highly dependent on landings of the Big 7 in comparison to their overall value of landings vary significantly among gear type, boat length, and MS. 14 fleets have landings value of greater than 50% coming from the NS Big 7. These include, for example, "under 10s (e.g., DNK DTS VL0010°) with low employment (6), 18-24m boats with high employment (e.g., GBR DTS VL1824, 1080 employed), and over 40 m TBB boats with high employment (e.g. NLD TBB 40XX°), 734 employed.

19 fleets have between 25% and 49% of landings value earned selling Big 7 species; 16 fleets have between 10% and 24% Big 7 value of landings; 24 fleets have less than 10% landings, 15 of which are 2% or less.

Table 5.3 - Top 11 Big 7 landings value compared to overall landings of the fleets

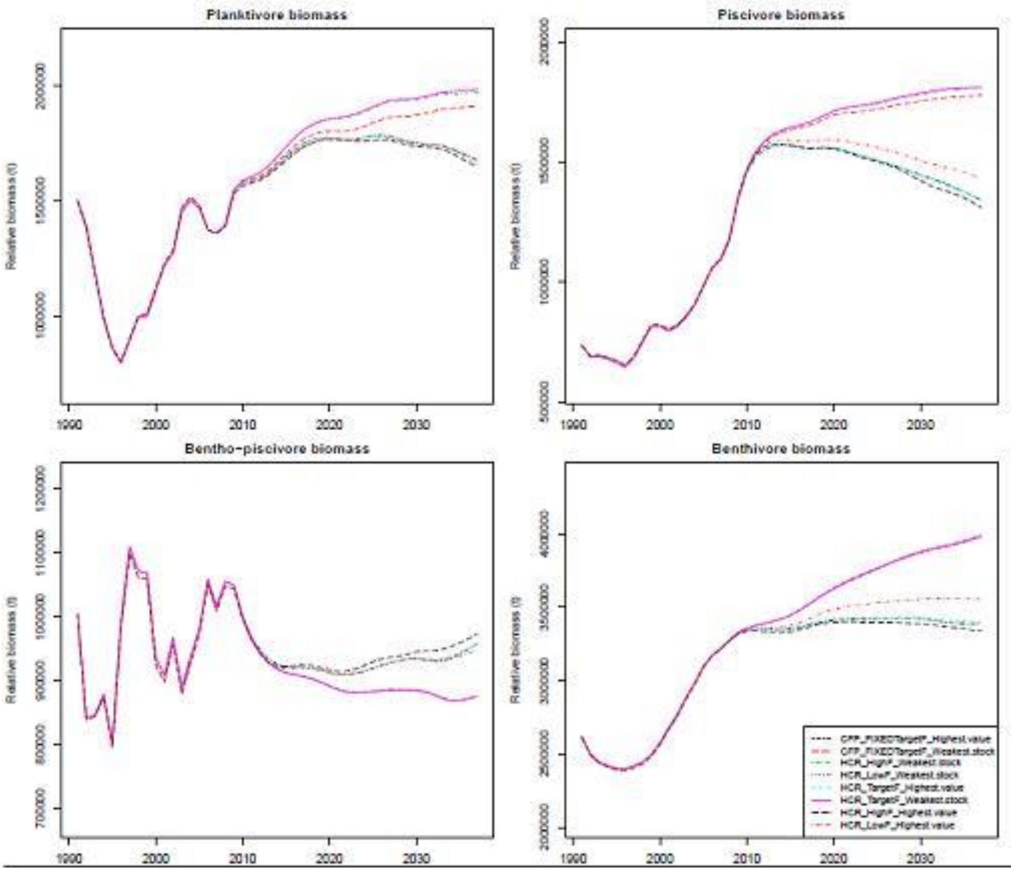
AER fleet segments	Employment in the fleet segment (number of employees)	Value of Big 7 in the NS compared to overall value of landings of the fleet
DEU AREA27 DTS VL2440°	55	80%
DEU AREA27 DFN VL1218°	16	74%
DNK AREA27 DTS VL0010°	6	72%
DEU AREA27 TBB VL2440	45	70%
DNK AREA27 PGP VL1218°	70	68%
NLD AREA27 TBB VL40XX°	734	67%
BEL AREA27 DTS VL1824	36	67%
DNK AREA27 PMP VL1824°	46	65%
NLD AREA27 TBB VL2440°	216	64%
NLD AREA27 DTS VL1824°	73	62%

It is important when evaluating dependency with a view towards impact assessment, to focus on fleet characteristics such as the location of the fleet and boat length (and profitability) as well as the percentage of the Big 7 landings in the North Sea compared to overall landings. Fleet DNK DTS VL0010°, for example, though only employing 6 individuals, receives 72% of their landings value from the Big 7. Furthermore, as an under 10 m fleet, fleet movement may be restricted. Thus, this may be considered an especially dependent fleet.

5.5 Biodiversity

Figure 5.14 presents a set of biodiversity indicators computed using the EwE model. Increases in biomass of large predatory fish predicted by the lowest quota scenario, are reflected in changes in the size composition of the fish (+elasmobranch) community. Mean maximum length and the Large Species Index are both predicted to increase. Under the maximum economics scenario, similar increases occur in the first 10 years of the forecast. This corresponds to a period of increasing biomasses of some large predatory fish resulting from decreases in fishing mortality. The latter half of the forecast predicts a slight decline, which appears to be as a result of increased abundance of marine mammal predators. Additional metrics of ecosystem indicators are shown in appendix II. Important features that emerge are (i) the drastic reduction of fishing under the lowest quota scenarios lead to increases both piscivorous and benthic biomass, but declines in other groups that are eaten by them (ii) under maximum economics scenarios the effects on higher trophic level species are (cascading up the food chain) are more apparent than the effects on lower trophic level species. (iii) fishing at the lower limit of the Fmsy range scenarios have more positive effects on species biomass that the Fmsy and fishing at the upper limit.

Figure 5.14 Biodiversity indicators from EwE



5.6 Reconciling TACs by using FMSY ranges

One of the most important elements of the new MAPS is the use of a range of values for the targets instead of a single value. The flexibility introduced through this mechanism allows the reconciliation of the TACs taking into account the mixed fisheries interactions, which can decrease undesirable limitations by single species on the use of the available fishing opportunities.

Figure 5.15 shows the realized fishing mortality in 2020 and the Fmsy target by stock, obtained with FCube for the baseline and the maximum economics scenario. It's obvious that in some cases the distance between the target and the realized fishing mortality is quite large, showing both under exploitation for haddock and saithe, and over exploitation for cod. The differences are the result of inconsistencies between the single species targets and the mixed fisheries interactions that occur when the fleets are using their fishing opportunities.

The Fmsy ranges allow the setting of targets differently within the range for the various stocks. As an example the EWG ran a simulation with FCube where for each year the TAC were set based on the following rule:

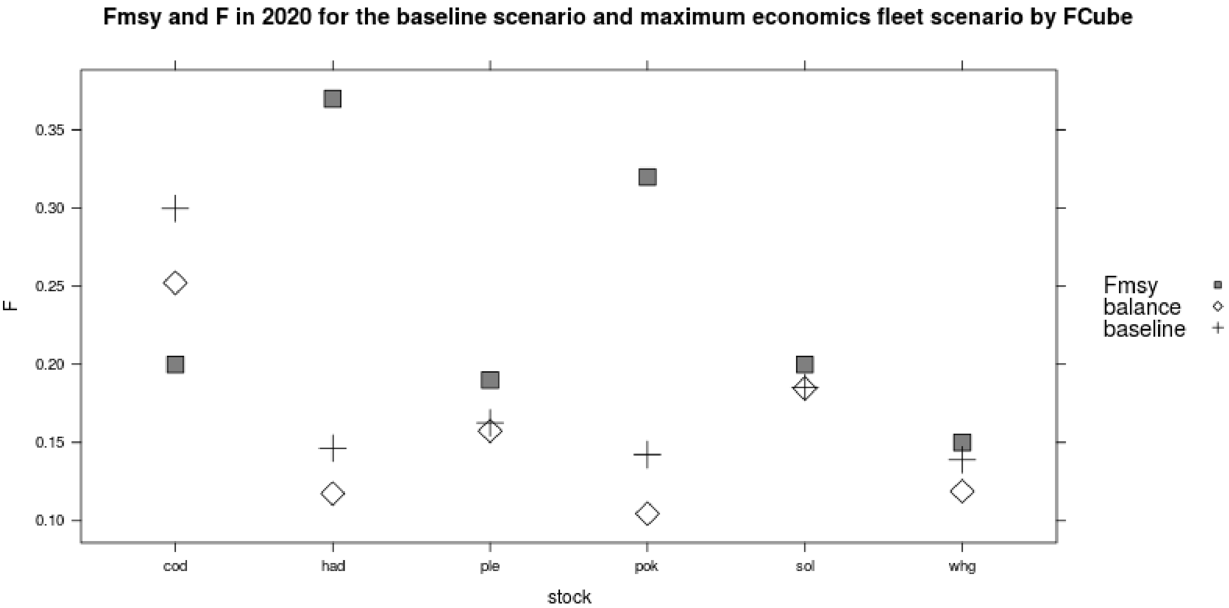
- If F in current year is whithin the Fmsy range then the F target is set at Fmsy point estimate,
- If F in current year is below the lower limit of the Fmsy range then the F target is set at the lower limit of the Fmsy range,
- If F in current year is above the upper limit of the Fmsy range then the F target is set at the upper limit of the Fmsy range,

which also included safeguards with a recovery period of 5 years.

The results are presented in Figure 5.15. The example shows that for cod it was possible to come closer to the target F than when managing without ranges, although for haddock and saithe F was further away.

What's important to retain is that it may be possible to better manage the stocks making use of the flexibility that the ranges provide. However, that can only be possible if the ranges are used to reconcile the TACs with the mixed fisheries interactions, which most likely will require adaptations in the advisory system to provide information about which options can be more effective achieving the CFP objectives under such conditions.

Figure 5.15 – Example of management option to better reconcile mixed fisheries interactions with TACs under the NS-MAP.



6 TOR B)

[*In addition, for stocks that are below B_{pa}, what are the consequences for fishing opportunities in the mixed fisheries if the stocks are rebuilt to a spawning biomass greater than B_{pa} within i) 5 years or ii) 10 years (i.e. possible values of [n] in point 4 a)? (Considering that NS cod is near B_{lim}, the impact of this is likely to be driven largely at the rate at which you can recover cod).*]

In ToR b), STECF was asked to consider what would be the consequences for fishing opportunities in the mixed fisheries if the stocks that are below B_{pa}, are rebuilt to a spawning biomass greater than B_{pa} within i) 5 years or ii) 10 years. It is recognised that this requirement is largely driven by the experience from the current cod plan, where the sharp short-term TAC reductions imposed in an attempt to recover North Sea cod to SSB levels further away from B_{lim}, have created political discontent and have resulted in increased discarding.

Attempts to address this request were performed with the Fcube model. A recovery phase was included in the F_{MSY} ranges scenarios, allowing a slower approach to reaching MSY than for those stocks above. The recovery is based on an F-target and not on a SSB target, following the "transition to MSY" approach used by ICES in its advice between 2009 and 2015. Here, we simulated a transition to the F_{target} (F_{MSY} or F_{MSY} range) by 2020 (5 years recovery) or 2025 (10 years recovery). For those years and iterations where the SSB is below B_{pa}, a F intermediate between the status quo and the target, consistent with the numbers of years left before the recovery date was used as input to Fcube.

As explained, it is not possible to predict with certainty what will be the future levels of fishing effort and the adaptation of fishing fleets, therefore the ToR is addressed by investigating the *robustness* of the plan to different recovery time. Robustness is mainly addressed by looking at the extreme Fcube scenarios MIN (=lowest quota) and MAX, as the range of possible options and the worst case scenarios.

The median trajectory of cod for the MIN Fcube run is shown below:

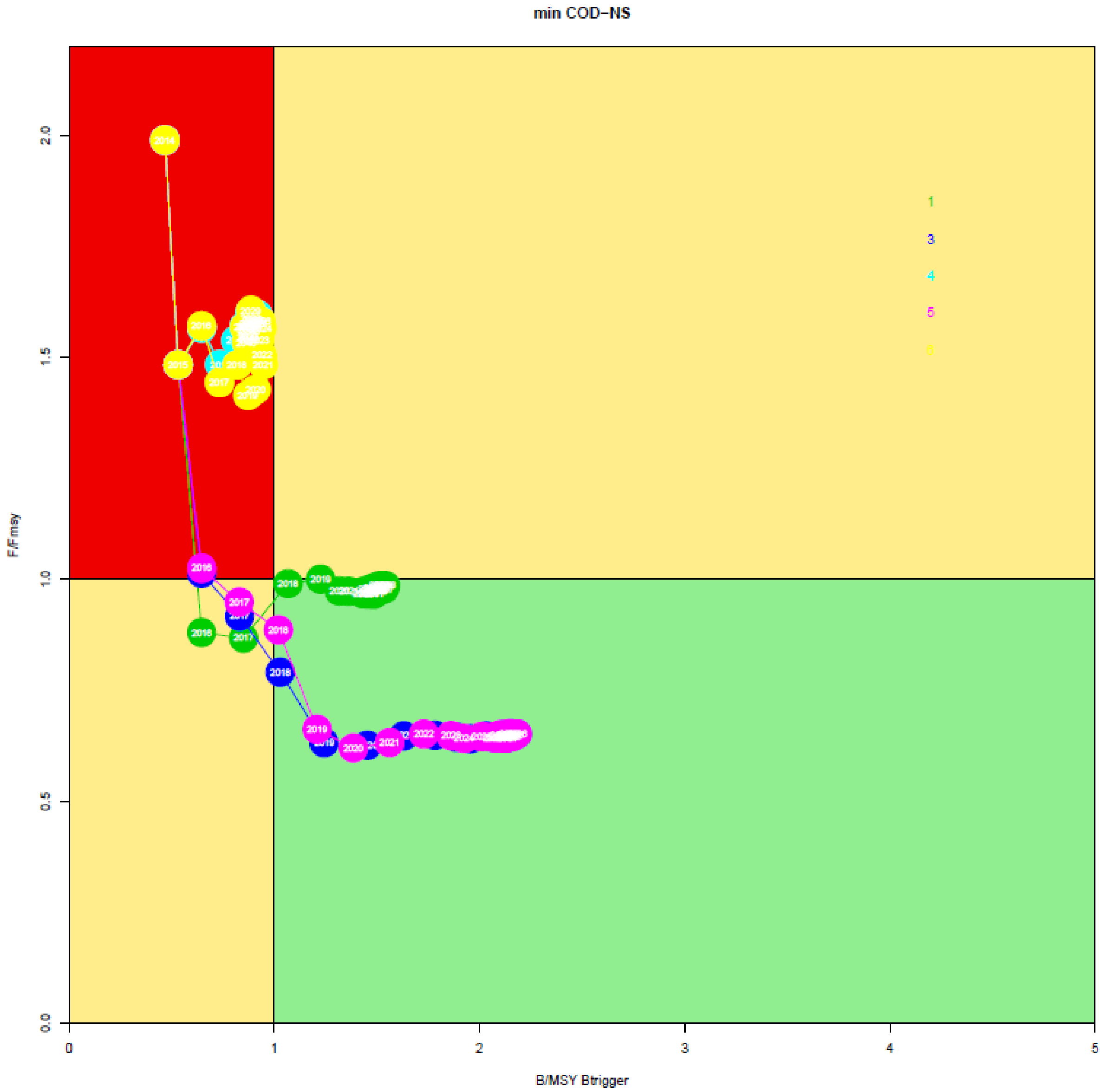


Figure 6.1. North Sea cod, Fcube run "MIN" (lowest quota) for different scenarios. Kobe plot (SSB/MSYBtrigger on x-axis, F/Fmsy on y axis) for the median value by scenario (in color) and year (each dot is a year). Green : baseline (scenario 1). Dark blue : Fmsy_low with fast (5 years) recovery (scenario 3). Pale blue : Fmsy_high with fast recovery (scenario 4). Purple : Fmsy_low with fast recovery (scenario 5). Yellow : Fmsy_high with slow recovery (Scenario 6)

For the MIN run, there is thus little effect of the recovery time for cod, and most of the dynamic is driven by the F_{MSY} target. However, some numerical instability appears in the simulations when using the MAX run, indicating higher uncertainty on future stock state and higher risk to biomass, and these instabilities appear worse with the slow recovery:

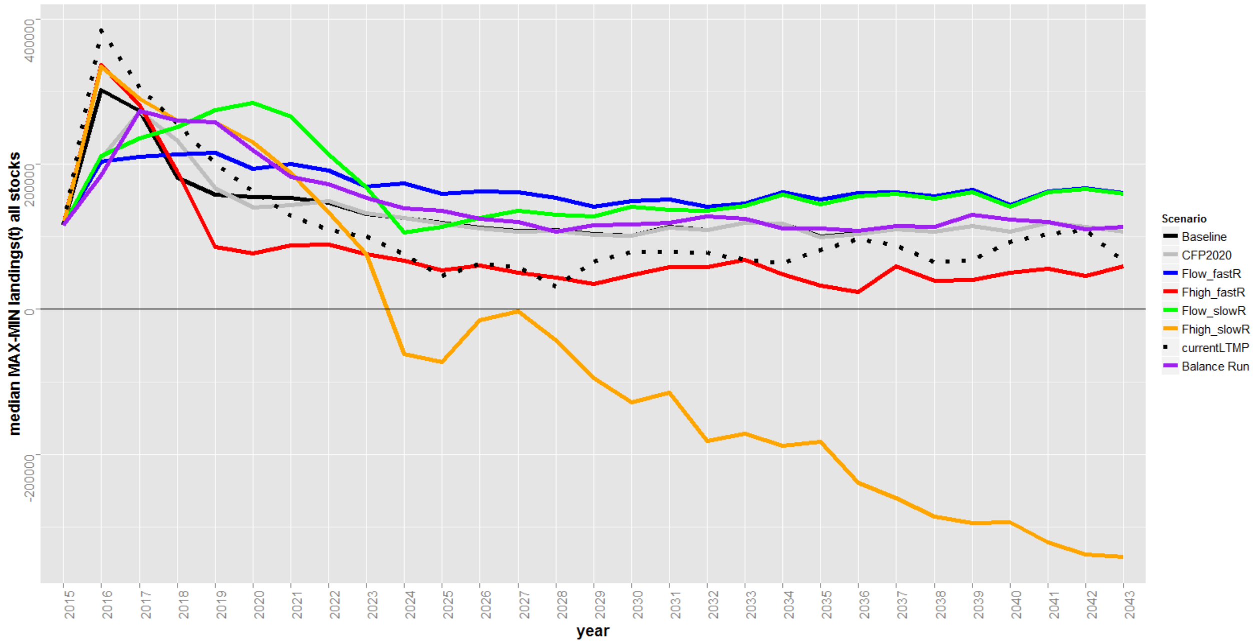


Figure 6.2. Median of the difference of total landings summed over all stocks between the Fcube Max and Fcube Min runs, for the 8 scenarios.

In the worst case scenario (Fmsy_High slow recovery), the slow safeguards mechanisms are not able to prevent stock declines, and in the max run, fish stocks become so overexploited that the catches after some years are lower than the catches with the min run (low effort).

In terms of *impact assessment* (using Maximum economics = "val" run), at stock level, the differences between a 5- or a 10 years recovery are not so strong (Figure 66.3). But mainly, the risk for cod of being below B_{lim} by 2020 is clearly reduced with the fast recovery scheme, getting close to the 5% used by ICES as the precautionary threshold, whereas the risk is around 15% with the slow recovery.

In the short-term (2016-2019), the impact of recovery rate on the fleets is very limited (Figure 6.4).

In conclusion, the Expert group considers that a fast recovery scenario (5 years) is better than a slow recovery, because it bears a smaller risk and smaller uncertainty to the future biomass levels, not least for cod, without making much difference to the fleets in the short term.

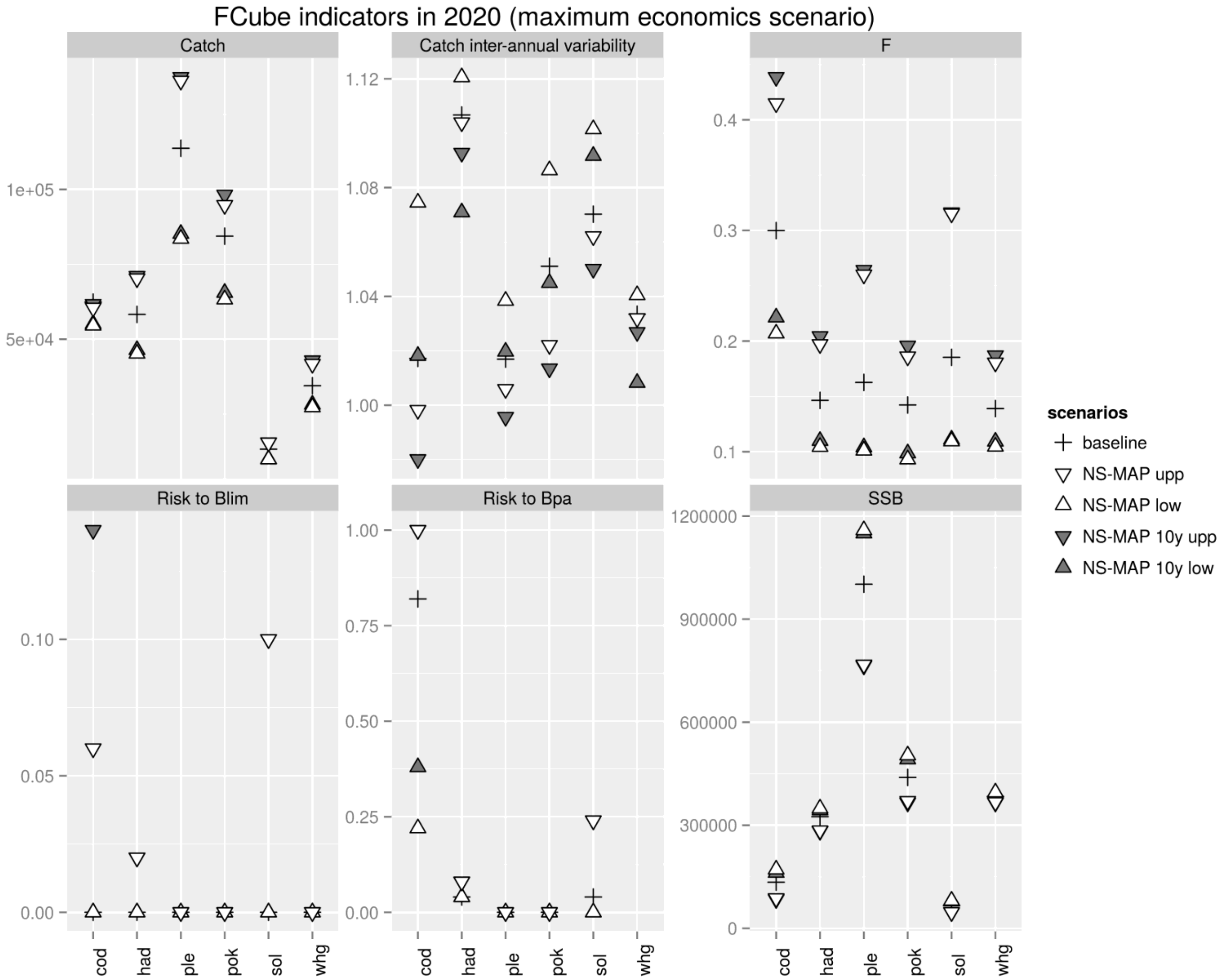


Figure 66.3. Biological indicators in 2020 for 5 scenarios, using Fcube “val” (maximum economics).

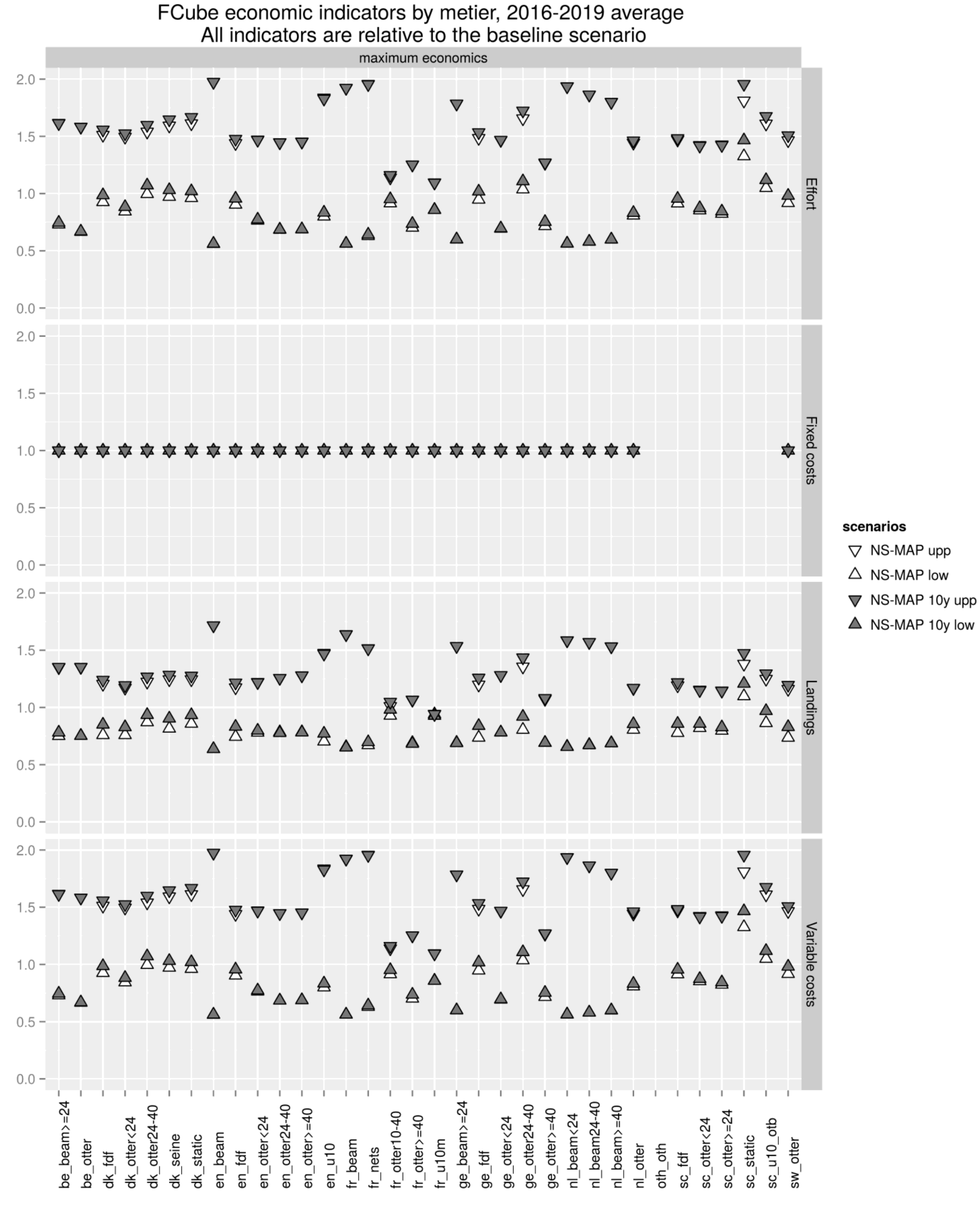


Figure 6.4. Economic indicators in 2020 for the 4 scenarios relative to baseline (scenario 1), using Fcube “val” (maximum economics).

7 ToR c)

[*Would by-catch stocks in the main fisheries be sufficiently protected through the management measures to achieve FMSY on the species defining the fisheries (see point a), or would one or more need specific conservation measures? Can the stocks that are likely to need specific conservation measures be identified?*]

To explore the potential impact of management measures applied to the “target” species into the “by-catch” species, the EWG used statistical correlation between catches of the “by-catch” and the main 6 stocks. The rationale is that if caught together, a management measure reducing or increasing the effort on one of the six main species might impact the other species part of the catch assemblage.

The data source was the STECF effort data base, built during EWG 14-13, which provides a detailed image of the catches and catch composition of the different gears operating in these areas.

Very few species appear to be correlated at stock level with these six main stocks. Only Pollack and Anglerfish catches appear to be correlated with Cod catches for example see Table 7.1 and Figure 7.1.

Table 7.1. Correlation between Cod catches and other species catches

MainSpp	ByCatch	CorrelationCoeff	CatchesMainSpp	CatchesByCatch
COD	POL	0.71	36950	1589
COD	ANF	0.55	36950	9945

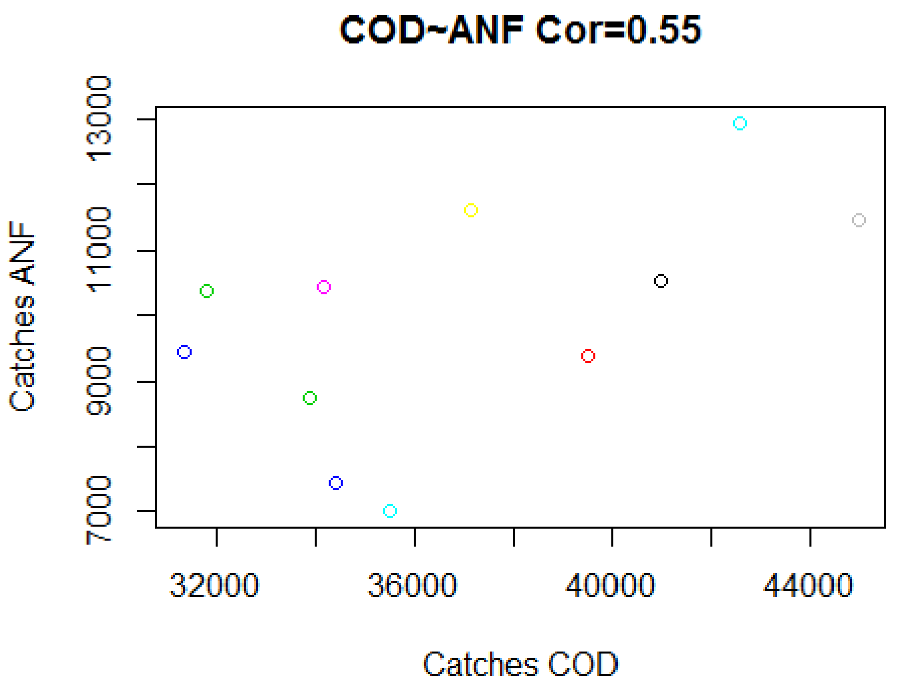


Figure 7.1. Relationship between Cod catches and Anglerfish catches over time (colors represents years)

Using the STECF database it is also possible to assess the yearly catch assemblage of the different gears and test for correlation between the level of catches of the main six species and catches of the other species in the database. When looking at the correlations between Cod and Anglerfish, it appears that TR1 in area 4, the main contributor to the total catches (more than half of the catches), shows a correlation between Cod and Anglerfish catches. However, other gears such as BT2 do not show any correlation between these two species.

Table 7.2. Correlation between Cod catches and other species catches for BT2

Met	MainSpp	ByCatch	CorrelationCoeff	CatchesMainSpp	CatchesByCatch
BT2.4	COD	DAB	0.77	356	5603
BT2.4	COD	TUR	0.91	342	293
BT2.4	COD	CRE	0.88	441	99
BT2.4	COD	BLL	0.93	216	69
BT2.4	COD	NEP	0.82	477	39
BT2.4	COD	BSS	0.91	490	36
BT2.4	COD	JAX	0.51	661	15
BT2.4	COD	SQS	0.75	105	5
BT2.4	COD	HKE	0.56	438	3
BT2.4	COD	LIN	0.55	68	0
BT2.4	COD	LEZ	0.77	322	0

Table 7.3. Correlation between Cod catches and other species catches for TR1

Met	MainSpp	ByCatch	CorrelationCoeff	CatchesMainSpp	CatchesByCatch
TR1.4	COD	ANF	0.87	1626	552
TR1.4	COD	HKE	0.7	1599	393
TR1.4	COD	LIN	0.74	1915	324
TR1.4	COD	LEZ	0.91	2441	187
TR1.4	COD	NEP	0.77	1749	170
TR1.4	COD	LEM	0.57	1573	166
TR1.4	COD	SQS	0.69	2115	102
TR1.4	COD	POL	0.73	1847	99
TR1.4	COD	WIT	0.51	1789	75
TR1.4	COD	CAT	0.8	2308	49

Looking at a more detailed aggregation shows that the relationship between the target-bycatch dynamics are stronger at the fleet level than the stock or métier level.

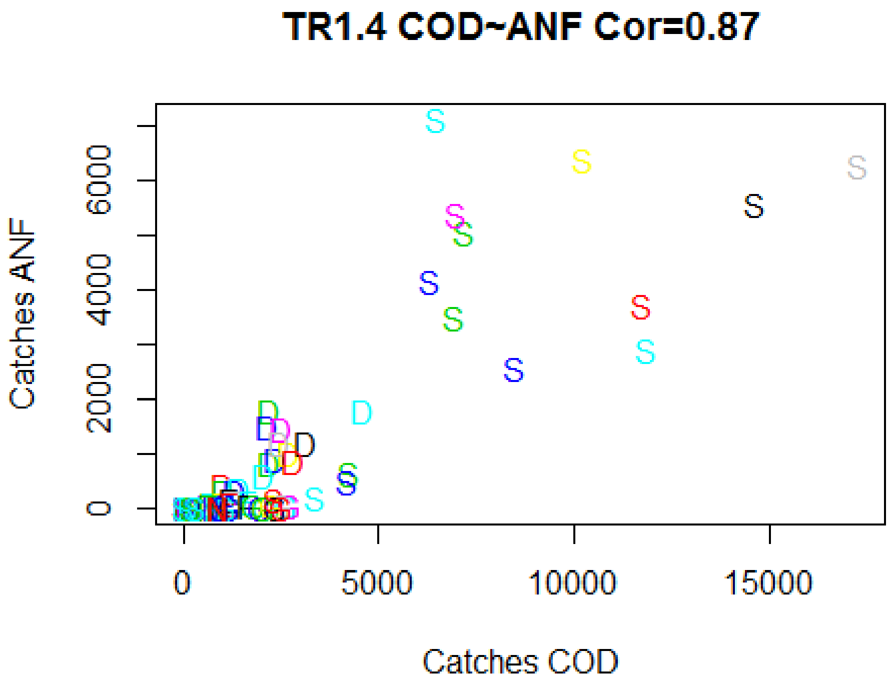


Figure 7.2. correlation between Cod catches and other species catches (colors represents years, letters countries)

It should be noted that in the effort database, catches are aggregated over years, métiers and areas. However, fleets and species move during the year (changing fishing ground, spawning migrations, etc) which means that observed correlations might not reflect real technical interaction. Correlations between levels of catches of the main species and the "other species" presented here should be taken as indicative of the potential impact of management on species caught by the different gears.

8 ToR d)

[*Based on the response to point c), what would be the advantages and disadvantages of grouping the by-catch stocks into an "other species" TAC? Are there any by-catch stocks for which individual TACs would be still recommended?*]

In practice, grouping stocks already occurs in the North Sea, and in other areas. For example, in the North Sea there are grouped TACs for turbot and brill, for flounder and dab, and for lemon sole and witch flounder. Likewise, skates and rays are currently managed under a grouped TAC. The status for these stocks is generally estimated separately for the individual stocks, using one of the Data Limited Stock methodologies in ICES. Often, this means the stock status is assessed using survey trends.

In theory, the considerations on the sustainability of combined TACs are similar if several species are combined, or if several stocks of the same species are combined. In the North Sea, several stocks of *Nephrops* are combined into a single TAC. Examples of grouping TACs can also be seen in other areas. In the Northeast Atlantic for example, there are grouped species TACs for monkfish and megrim: the two species of monkfish sharing a single TAC, and two species of megrim sharing a single TAC.

One of the problems with addressing this ToR is the use of the term "by-catch", without specifying exactly what it entails. There are many different definitions of "bycatch". In the description of advantages and disadvantages of grouping quota that is given below, “bycatch” is defined as catches that are caught unintentionally while catching target species and target sizes. Bycatch can either be of a different species, or the undersized or juvenile individuals of the target species. However, what is a target species and what is a bycatch species depends on the fishery, and different vessels within a fleet may have different target species and bycatches. If combined TACs for so-called bycatch species are introduced, there will be a need to precisely define which species constitute the bycatch and this may need to be specified separately for different fisheries.

One of the **advantages** of combined TACs is that it provides increased flexibility for fishers to deal with the variability in bycatches. Hence catches within a quota can be substituted, so the species that potentially choke a fishery can be substituted by other species thereby allowing fishing on the target species to continue. Such increased flexibility could also improve the reporting of catches taken under the bycatch quota, because there would be less of an incentive to under- or mis-report the by catch species.

Furthermore, setting individual quotas for species that have until now been largely discarded is surrounded with a high level of uncertainty. Combining stocks may alleviate the problems with setting quota for such species individually, and create a buffer against uncertainty in the assessment and management of such stocks.

One of the **disadvantages**, by definition, is that combined TACs do not necessarily constrain the catches of individual species, because substitution between species subject to the combined TAC may take place. This could lead to overexploitation of some species, especially when combining vulnerable and invulnerable species.

The amount of substitution depends on several factors:

- the species composition and relative weight of those species in the bycatch: a large difference in the catch weights allows for easy substitution of a relatively large part of a small catch with a relatively small part of a large catch.
- the differences in net economic benefit (depending on price, and costs of exploitation) of the different bycatch species: a large difference in net economic benefit will generate an incentive to substitute lower value species with higher value species.

While one of the potential benefits of combined quotas is a reduction in the underreporting of catches, in the long run there is a risk of mislabeling of catches for pooled species that have a similar appearance and market price. This has previously been observed with anglerfish, skates and rays.

As mentioned above, to introduce combined TACs for bycatches, the terms “bycatch” and “target” need to be clearly defined, perhaps on a fishery or fleet basis. If vulnerability to overfishing of the by-catch species that comprise the combined TAC is considered a flexible system in which the grouping is regularly evaluated. The costs of monitoring and managing such a system are likely to be high.

In order to **mitigate** the above disadvantages, the species composition of mixed-species TACs would need to be tracked to monitor the changes in the catchability and the vulnerability of the bycatch species to overfishing.

Combining species of different vulnerabilities that have large differences in price, and large differences in catch volumes should be avoided. There are a range of sources available for this information. For example, information on vulnerability indices by species (from Cheung et al. 2005, based on life history parameters) can be extracted from FishBase; prices can be found in the STECF Annual Economic report database; data on stock and catch status can be extracted from the STECF Consolidated Review of Advice and from ICES.

Finally, under a precautionary approach the combined-species TACs could be set lower than the sum of the individual species TACs to account for the increased risk of overexploitation of the individual species, due to the uncertainty associated with the conservation of the species grouped in a single TAC.

9 CONCLUSIONS

The evaluation of the Management Plan proposal carried out by the EWG provides a general comparison of the expected outcomes of managing this fishery under the basic CFP regulation or under a specific plan that incorporates the available knowledge on species and fleet interactions. This knowledge is currently still partial and does not allow a full evaluation of the risks associated by all management options.

This evaluation is also limited by the lack of a formal mechanism to decide on yearly fishing opportunities, generally in the form of a Harvest Control Rule or another similar algorithm, in the Management Plan. Estimations of future performance and the associated risks can only be carried out by assuming what the decision making body will do when confronted with various signals on stock status. The final ability of all of the management options under analysis to deliver the objectives will be contingent on management decisions deviating or not for those implicit in the plans analyzed.

The impact of the Landings Obligation (LO) cannot be precisely evaluated at this time. The likely changes in effort allocation, fleet catchability and selectivity, and catch composition cannot be predicted at the moment given the available information and our knowledge of the fleet dynamics, but also given the existing uncertainty in the precise implementation of the LO policy in some fisheries. The analyses presented here have assumed that the LO policy will be implemented fully.

Any attempt at simultaneously managing a number of stocks at precisely F_{MSY} levels is bound to fail, given the levels of natural variability in fish populations, and the dynamics of fleet activity. Trade-offs will have to be accepted between conservation of some stocks and full exploitation of others.

Inconsistencies between targets for different stocks appear to be larger for the baseline scenarios, which attempt to achieve F_{MSY} levels of exploitation for all stocks. Fishing opportunities can more easily be reconcile when the flexibility provided by the F_{MSY} ranges is used, as in the management plan scenarios presented above. Although individual F_{MSY} values are still the plan targets, actual F_{MSY} values are allowed to fluctuate around them while inside the ranges, so conservation action would only need to be triggered when even the range limits are exceeded.

The need for recovery of the North Sea cod stock is likely to affect the fishing opportunities for other stocks and fleets where cod is caught mainly as by-catch in the near future, even under a management plan based on F_{MSY} ranges. The choice is between a rapid recovery of cod, with short term losses in catch of other stocks, and a longer recovery, thus extending the 'choking' effect that management measures for cod have on the fisheries that target them.Given the complex interactions between fleets and stocks, and the narrow range of balance across all stocks, protections against implementation error and ensure safe biomass levels for all stocks need to be built into the management system. Biomass safeguards for all stocks should still be maintained and should provide a basic level of protection in this case.

Adopting F_{MSY} ranges could in some cases increase the risk of overfishing across some or all stocks, particularly if a decision is taken to fish at the upper levels of those ranges. The benefits that could be obtained, in terms of flexibility and adaptability, would then be lost as inconsistencies on status and management needs across stocks would likely increase. The probability of stocks falling below B_{pa}/B_{lim} reference points appears to be substantially higher. In the long term, the fishery would be expected to be less profitable, as catch rates would decrease while exploitation costs remain constant.

Increasing the flexibility of the system, while potentially allowing it to better accommodate to the tensions and contradictions expected from such a wide range of fleets and stocks operating in combination, will also introduce greater uncertainty in our ability to forecast the responses of those stocks to future exploitation rates and the responses of all fleets to changes in fishing opportunities. The constraints in annual changes in TAC, present in past regulations, helped keeping the system stable with advantages both for the fleet and the stocks and could be maintained on future regulations.

The combination of changes in the basis for advice, either under the CFP rules or MAPs, will require adaptation of the advisory process to include a more explicit recognition of the multi-species and multi-gear nature of this fishery.

Bringing fishing levels closer to F_{MSY} could increase the influence of biological interactions in the system. Natural mortality, partly driven by prey-predator interactions, would play a bigger part in stock abundance. Population dynamics and seasonal dynamics of the fishery under the new conditions would have to be further investigated to better understand the increasing role of natural relationships in the North Sea fish stocks.

Relying on the management of the species that drive the fisheries to manage the non-driver species to the levels of conservation required by the CFP is likely to be ineffective. Most, if not all, fleet dynamics regarding the target species occur at the fleet level, which are not directly affected by TAC, rather indirectly in the case where Member States partition their quota to vessels or associations.

Grouping a number of single species TACs could introduce additional flexibility in the management of this system. However, the trade-off is that the potential to overexploit some stocks appears to increase. A set of mitigation principles were identified which should be considered if grouping of single species TACs is finally included in a management plan. Intense and strict monitoring will be essential to ensure that non-target species, or those less easily identified, are not overfished. The inclusion of fishing effort controls should also be considered in this case.

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11 CONTACT DETAILS OF STECF MEMBERS AND EWG-15-02 LIST OF PARTICIPANTS

1 - Information on STECF members and invited experts' affiliations is displayed for information only. In some instances the details given below for STECF members may differ from that provided in Commission COMMISSION DECISION of 27 October 2010 on the appointment of members of the STECF (2010/C 292/04) as some members' employment details may have changed or have been subject to organisational changes in their main place of employment. In any case, as outlined in Article 13 of the Commission Decision (2005/629/EU and 2010/74/EU) on STECF, Members of the STECF, invited experts, and JRC experts shall act independently of Member States or stakeholders. In the context of the STECF work, the committee members and other experts do not represent the institutions/bodies they are affiliated to in their daily jobs. STECF members and invited experts make declarations of commitment (yearly for STECF members) to act independently in the public interest of the European Union. STECF members and experts also declare at each meeting of the STECF and of its Expert Working Groups any specific interest which might be considered prejudicial to their independence in relation to specific items on the agenda. These declarations are displayed on the public meeting's website if experts explicitly authorized the JRC to do so in accordance with EU legislation on the protection of personnel data. For more information:

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12 LIST OF BACKGROUND DOCUMENTS

Background documents are published on the meeting's web site on:
http://stecf.jrc.ec.europa.eu/web/stecf/ewg1502

List of background documents:

1. EWG-15-02 – Doc 1 - Declarations of invited and JRC experts (see also section 11 of this report – List of participants)
2. Biomass, catch and fishing mortality trajectories.Summary datasets

ANNEX I – FCUBE DESCRIPTION

I.1 Model description

The Fcube model (Fleets and Fisheries Forecast, Ulrich et al., 2011) was first initiated by ICES in 2006, with the aim of quantifying the technical interactions among stocks being caught simultaneously, and the impact of these on single-stock management. Over the time, the model has evolved to incorporate more and more features (see the suite of ICES WGMIXMAN/WGMIXFISH reports since 2006), and has been routinely used for producing mixed-fisheries considerations for the North Sea demersal fisheries as part of the ICES advice since 2009.

The model builds on a fairly simple idea: Assuming that catchability and effort patterns are unchanged compared to the last data year, F-based fishing opportunities for each stock can be translated into an equivalent level of effort for each fleet ("effort-by-stock"). And since each fleet can only have a unique amount of total effort over one year, this effort is calculated as a scenario across the various equivalent effort-by-stock :

1) max: The underlying assumption is that fishing stops when all quota species are fully utilized with respect to the upper limit corresponding to single-stock exploitation boundary. NB: "MAX" here is not equivalent to the "maximum economics" used throughout this report, as this extreme run is not considered a very plausible future and cannot be used for impact assessment.

2) min: The underlying assumption is that fishing stops when the catch for the first quota species meets the upper limit corresponding to single-stock exploitation boundary.

3) sq_E: The effort is set as equal to the effort in the most recently recorded year for which landings and discard data were available (2013 here)

4) val: The underlying assumption is that fleets are inclined to fish for the quotas that provide most revenues, and the effort is set at the mean across the various effort-by stock-levels weighted by the value of the fishing opportunity by stock (landings*mean price). In the absence of a real economic behavior modelling, this run is used as the proxy for the plausible future in terms of impact assessment , referred as "maximum economics" in the report throughout – for standardization with other models' runs.

These scenarios are very coarse, and none of them can be considered realistic. Nevertheless they frame the range of plausible parameters space, and allow comparing the magnitude of discrepancies or unbalance in the overall North Sea demersal fisheries. ICES WGMIXFISH considers that existing behaviour models are not able to predict accurately the processes of adaptation and decision of individual fishing businesses, and cannot thus be used to derive a single quantitative mixed-fisheries prediction for future fishing opportunities. Therefore, the mixed-fisheries considerations in ICES advice have built on the idea that incentives to overquota discards would be reduced if a better balance could be obtained between the fishing opportunities of the various stocks. As such, if imbalance would be reduced, this would also contribute to a better implementation the EU Landings Obligation with less of the perverse incentives to discard created by the quota regulation itself.

I.2. IMPLEMENTATION OF BASE SCENARIO

The MSE used in this report is largely similar to the one described in ICES WGMIXFISH-METH (2014) report. An important feature of the results presented here is that the scenarios do not involve any a-priori constraints on effort by fleets, neither as an upper bound nor as a limit on changes from year to year. While it is obvious that effort levels might not always be realistic because of economic realities of the fleets, it was decided to let the model operate as freely as possible to achieve a real comparison of the management scenarios themselves without hitting hidden constraints. Exploring the entire parameter space is useful to understand the numerical interactions and potential cascading effects that may create instability and increased risks in the system. Restraining parameters within more plausible values is only required afterwards in the impact assessment part.

The main features of the model are as follows:

Conditioning of the stocks :

- FLR FLStocks objects from the 2014 WGNSSK assessment
- Hockey Stick stock recruitment relationships parameterized as :
  - Cod : since 1998 only, with breaking point at lowest observed SSB (assumption of continued low regime)
  - Haddock : since 1988 (recent low recruitment)
  - Saithe : since 1988 (recent low recruitment)
  - Whiting : with breaking point at lowest observed SSB
- Lognormal residuals of the SRR

Conditioning of the fleets :

- FLFleets objects from the 2014 WGMIXFISH (37 fleets, 95 combinations of country*vessel type*vessel size*gear and mesh size used*area)
- No age distribution in the fleets and métiers data
- Catchability, price and effort share as in 2013
- Fixed and variable costs fitted on AER data following the methodology from WKBEM 2013

Set up of the MSE

- 50 iterations running on 30 years (2014-2043)
- No observation error (no uncertainty in catch estimates) and no assessment error (no uncertainty in stock estimates)
- Full and perfect implementation of landings obligation from 2016 (no discards, all catches as landings)
- Feed-back loop (2 years short-term forecast with “pseudo HCR scenario” gives a quota that applies subsequently in the Operating Model, giving true F and SSB)
- True TACs in 2014 and 2015
- Single-species run (no technical interactions) OR Fcube implementation error:
  - F by stock from the OM used to calculate effort-by-stock for each fleet in TAC year

- Fcube scenarios resulting in a given effort level by fleet
    - Recalculating partial F by fleet and stock, and summing up by stock
    - Replacing F by stock in the OM by the new F including implementation error
    - Re-projecting the OM in TAC year for new catch, F and SSB after implementation error

Baseline Scenario (Scenario 1)

- Fmsy target point : Cod=0.2, Haddock=0.37, plaice=0.19, saithe=0.32, sole=0.2, whiting=0.24
- Implemented in 2016
- No constraint on TAC interannual variability, no sliding rule, no constraints on effort changes
- Single-species run + 4 Fcube runs

I.3 OTHER SCENARIOS

CFP 2020 (Scenario 2)

- Fmsy target point implemented in 2020
- Transition towards Fmsy from 2014 to 2020 (for each year, calculate the difference between Fcurrent and Fmsy, and the number of years left before 2020; calculate the F step to be reached in one year (linear change in F); target F for the next year is Fcurrent-step
- Rest as in scenario 1

The NS-MAP scenarios: *Fmsy ranges with safeguards (Scenarios 3 to 6)*

- Fmsy high range or low implemented in 2016
- For the stocks and iterations where SSB is below Bpa, recovery program to be reached in 2015 + n years (linear decrease from Fcurrent to F target as in scenario 2 above)
    - Scenario 3 : Fmsy_Low (NS-MAP lower), fast recovery n =5 years
    - Scenario 4 : Fmsy_High (NS-MAP upper), fast recovery n =5 years
    - Scenario 5 : Fmsy_Low, slow recovery n =10 years
    - Scenario 6 : Fmsy_High, slow recovery n =10 years

Current LTMP (Scenario 7)

- Current single-species target and HCR as implemented in ICES advice 2014
- Includes a TAC interAnnual variability of 20% (cod) or 15% (all other stocks)
- Includes a sliding rule if SSB falls below MSYBtrigger for cod, haddock and saithe

The Balance Run (Scenario 8)

- Run illustrating the possibility of setting targets differently within the range for the various stocks:

- For each year and each iteration and each stock:
    - If Fmsy_Low < Fcurrent < Fmsy_High then Ftarget=Fmsy point estimate
    - If Fcurrent<= Fmsy_Low then Ftarget=Fmsy_Low
    - If Fcurrent>= Fmsy_High then Ftarget=Fmsy_High
- Including also the fast recovery (n=5 years) mechanism

I.4 INDICATORS COMPUTED

Standard biological indicators

The following indicators were computed :

meanF : (median over iteration of the) mean Fbar over the period 2016:2023

mean Landings : same for landings

meanSSB : same of SSB

recove.rate : proportion of the iteration having fallen below Bpa who recover

recov.time : recovery time for those iterations

risk2Bpa : proportion of the iterations falling at least once under Bpa during the same period

risk3Blim : risk of falling below Blim

varTac : interannual variability in the landings

Economic indicators

Fcube did not previously include economic indicators, beside information on the catch value that is collected by ICES WGMIXFISH. Ahead of the NS-MAP meeting some work was performed to derive standard economic data (fixed costs, variable costs), updating the methodologies and outcomes initiated in 2013 by WKBEM. Full methodology on the estimation of costs for Fcube could be found in the Annex V of this report.

Other Fcube indicators

ICES WGMIXFISH initiated the exploration of synthetic Fcube indicators that could potentially describe the overall level of unbalance in the system (Ulrich et al., 2014).

As MAX and MIN represent the range of effort levels between the most and the least restrictive fishing opportunities by stock for each fleet, it can be assumed that the lowest the difference between the two, the least unbalance there is between TACs. Similarly, the difference between SQ and MIN can be used as a proxy for potential choke effects (how much reduction is needed compared to the current situation to achieve the minimum scenario). Both indicators can be computed for the whole fishery (sum over all stocks and all fleets), or individually for a more targeted impact assessment. Also, it can be computed on effort or on catches, in tonnes or in value.

$\Delta m = (\sum max - \sum min)$

$\Delta sq = (\sum sq - \sum min)$.

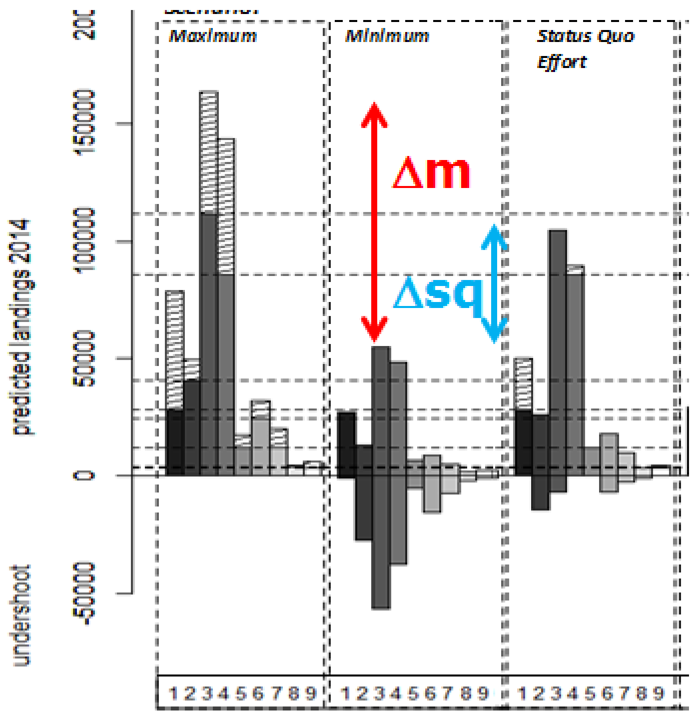


Figure 1.

I.5 Results

Simulations like here produce a lot of results (30 years * 50 iterations * 6 stocks * 8 management scenarios * (4 Fcube runs + one single-stock run) = 360 000 lines!), and synthetic outcomes summarizing the main features are required. Results are therefore analysed sequentially as follows :

1) **Performance** of the different management scenarios in a single-stock context without accounting for technical interactions – What would be the outcomes under perfect implementation?
2) **Robustness** of the different management scenarios to an imperfect implementation where the true catches for each stock differ from the expected catches due to the largest possible quota overshoot ("Max" scenario) or undershoot ("Min" scenario). As explained above, while these scenarios would likely not happen in the real life, their outcomes is interpreted as a measure of unbalance: The more the max and the min outcomes deviate from each other, the more discrepancies there are between fishing opportunities across the different stocks, and the more risk there is that the fisheries will deviate from the single-stock predictions
3) **Impact assessment** of the different management scenarios on stocks and fleets. In the absence of an accurate prediction of future effort levels by fleet, the impact assessment is based on the "val" Fcube scenario

Performance of management scenarios in single-stock context

The worst case scenarios, scenarios 4 and 6 with Fmsy_High do not perform very well under the assumptions of poor recent recruitment. On average, many stocks are driven close to MSYBtrigger and stabilize around it, except plaice which maintains high levels of biomass throughout. Other scenarios with F at Fmsy or Fmsy_low bring stocks well within sustainable limits in a few years. Notably, the scenario 7 which is the current single-species LTMP performs well for all stocks but cod, for which a target F of 0.4 is clearly too high under the hypothesis of poor recent recruitment – the sliding rule reduces fishing mortality and the stock increases, but as soon as the stock recovers above Bpa then the F increases again at 0.4, which in turns decreases the biomass again.

Robustness of management scenarios to mixed-fisheries implementation error

Mixed-fisheries interactions imply that catches can be larger ("max") or lower ("min") than expected in the single-stock context. Higher catches bring stocks lower down, and if the "max" approach is repeated many years in a row, cascading effects emerge in the simulations: as a higher effort would be necessary to fish the most productive stocks at Fmsy_high (e.g. plaice and haddock at the start of the time series), this would affect the most overexploited ones (e.g. cod and saithe), and at equivalent TAC the true F would be higher if the biomass is lower. In turns, this higher F implies again that a higher level of effort would be necessary to catch up the TAC for these stocks, which can also bring the F higher for another set of stocks (e.g. whiting and sole) in the following year etc.

When such cascading effects are evidenced in the simulations, one may argue that they may not happen in the reality because mechanisms would likely be put in place before reaching those poor situations. But they indicate nevertheless that the management scenarios creating these are unstable and risky, and should not be recommended.

The global indicators of robustness, DeltaM and Delta Q are computed for the whole system (sum of landings for all stocks)

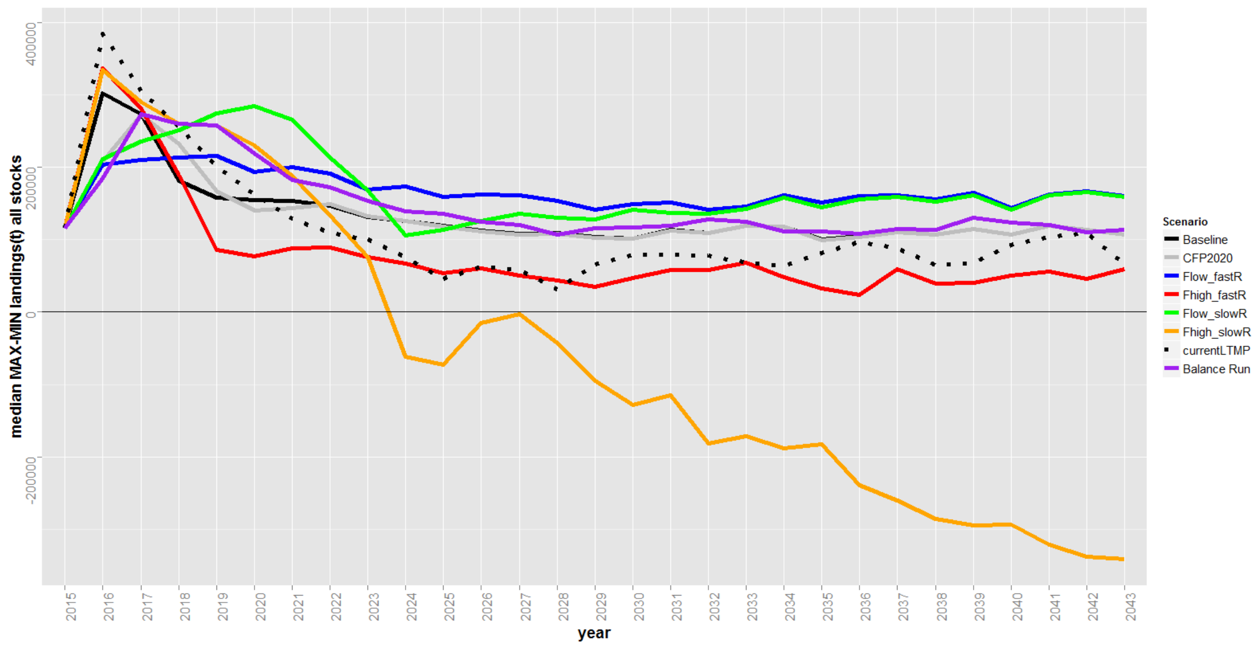


Figure 2. Median of the difference of total landings summed over all stocks between the Fcube Max and Fcube Min runs, for the 8 scenarios.

The worst case scenario Fmsy_High slow recovery is not robust to mixed-fisheries assumptions. The slow safeguards mecanisms are not able to prevent stock declines, and in the max run, fish stocks become so overexploited that the catches after some years are lower than the catches with the min run (low effort). Interestingly, the Fhigh scenario (red line) stabilize at a level where the differences in catches between max and min is very low, but based on widely different stock trajectories : over the long term, the min run delivers low catches with high stocks and low effort, while the max run delivers equally low catches but with high effort and low stocks, as is illustrated in the stock trajectories below:

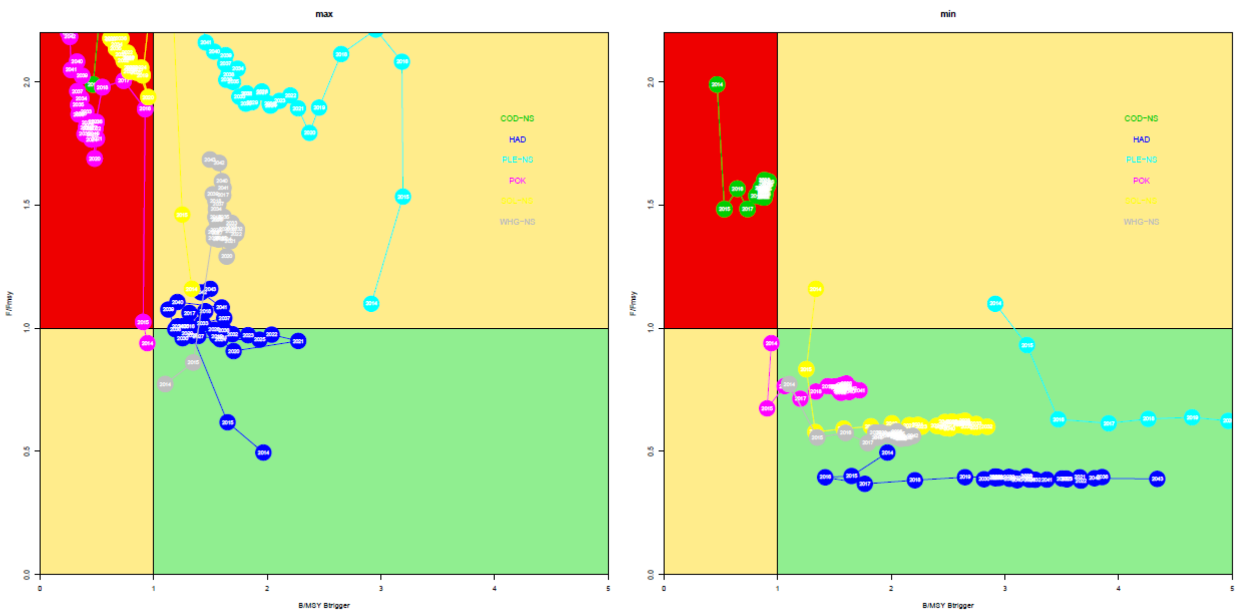
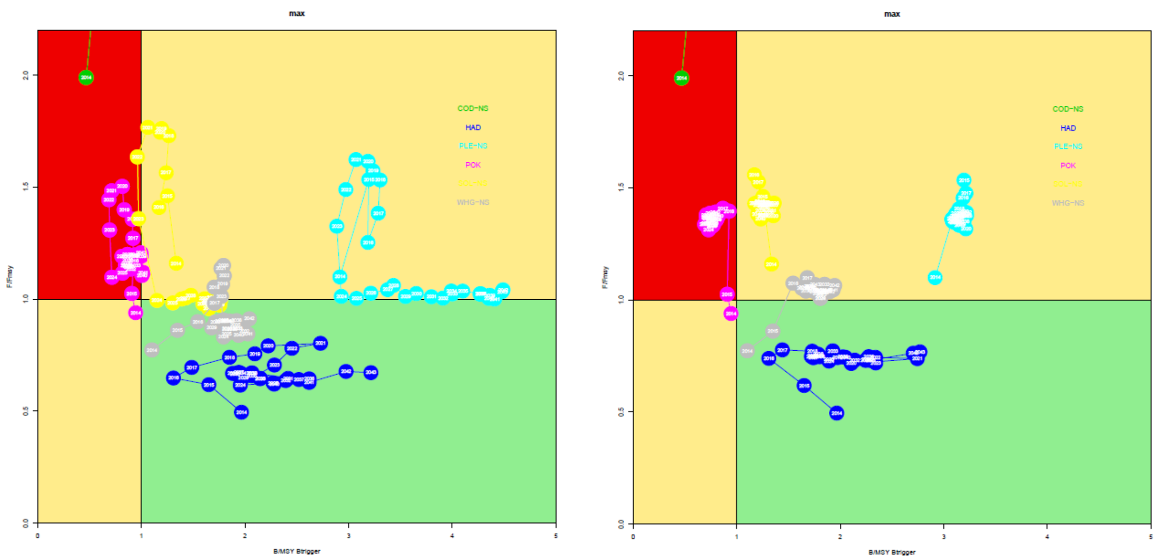


Figure 3. Scenario 4, Fcube run Max (left) and Min (right). Kobe plot (SSB/MSYBtrigger on x-axis, F/Fmsy on y axis) for the median value by stock (in color) and year (each dot is a year).

In other runs, all stocks but cod and, to a lesser extent saithe, are robust to mixed-fisheries assumptions, and can sustain higher catches than assumed in the single-stock context. But cod is never brought anywhere near the sustainable limits if the max run is assumed, even when the target is Fmsy_low.



Scenario 1 max and scenario 5 max

Figure 4. Scenario 1, Fcube run Max (left) and Scenario 5, Fcube run Max (right). Kobe plot (SSB/MSYBtrigger on x-axis, F/Fmsy on y axis) for the median value by stock (in color) and year (each dot is a year).

This indicates that cod is still the stock driving most considerations on mixed-fisheries management plan in the short- and medium-term, as it has been the case over the last many years.

Impact assessment of management scenarios including mixed-fisheries assumptions

In order to perform a sensible impact assessment, it is necessary to have a plausible scenario for how the fleet might react and set their effort. Therefore the MIN and MAX scenarios cannot be used for this, since they are extreme scenarios which are little realistic.

In the absence of a full mechanistic algorithm calculating a plausible level and distribution of effort, the impact assessment were run with the “val” Fcube run (=maximum economics).

Using this run, the impact of the different scenarios on cod is shown below:

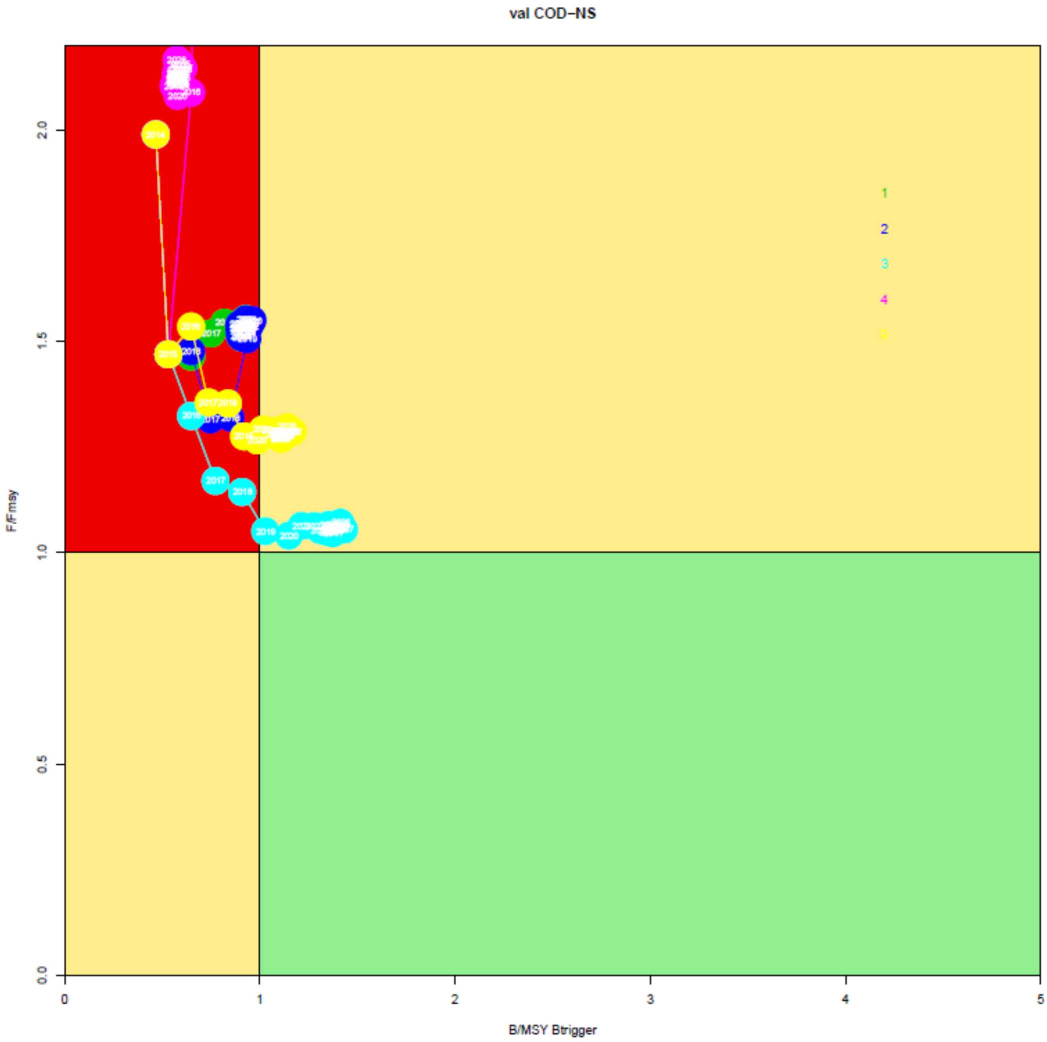


Figure 5. North Sea cod, Fcube run "val" for different scenarios. Kobe plot (SSB/MSYBtrigger on x-axis, F/Fmsy on y axis) for the median value by scenario (in color) and year (each dot is a year). Green : baseline (scenario 1). Dark blue : CFP 2020 (scenario 2). Pale blue : Fmsy_low (scenario 3). Purple : Fmsy_high (scenario 4). Yellow : Balance run (Scenario 8)

Interestingly, we show here that the balance scenario might eventually drive the cod towards a better state than the baseline. This is likely due to the fact that the balance run picks up a lower target F for haddock than the baseline run, which reduces the haddock-related effort-by-stock, and this brings the resulting simulated effort lower.

To measure the impact, we also compare the results with the "sq_E" run, i.e. what are the changes compared to maintaining effort at its 2013 level. At sq_E run, all scenarios are equivalent because the effort does not change and neither does the fishing mortality, regardless of the target.

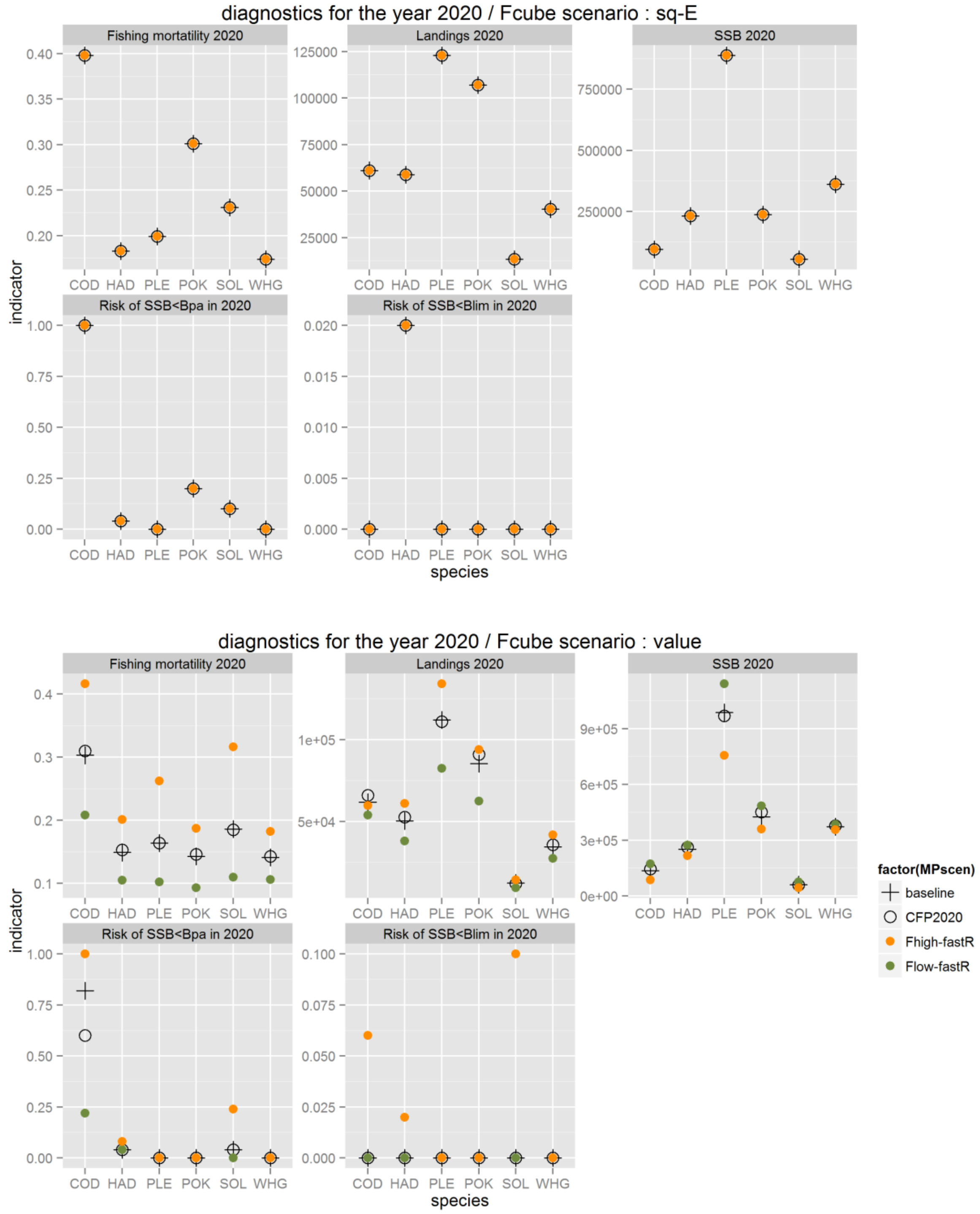


Figure 6. Comparison of biological indicators between the "status quo" Fcube run (top 8 panels) and the "val" (Maximum economics) run (bottom 8 panels, showing scenarios 1 to 4

Baseline scenarios lead almost systematically to lower F and higher SSB in 2020 with the "val" run than the sq_E run, whereas the Fmsy_high scenario can potentially be more risky to cod SSB than the current effort, due to the potential cascading effects of effort increase.

In terms of basic economic indicators by fleet (effort, landings and variable costs), using Fmsy ranges instead of Fmsy point estimates can lead to different outcomes for the different fleets (figure XX below). Usually, the fleets targeting flatfish show a greater range of plausible effort, with some increases compared to the baseline. The most noticeable result is that by 2020, the potential total landings by fleet are almost the same between the baseline and the NS-MAP upper (Fmsy_High) scenarios, for up to 50% more effort. This implies that fishing consistently at Fmsy_High returns positive gains only in the short-term, but this fades quickly away. After few years, lower CPUE (As the stocks would be lower) and higher costs for the same revenue indicate a poorer economic return.

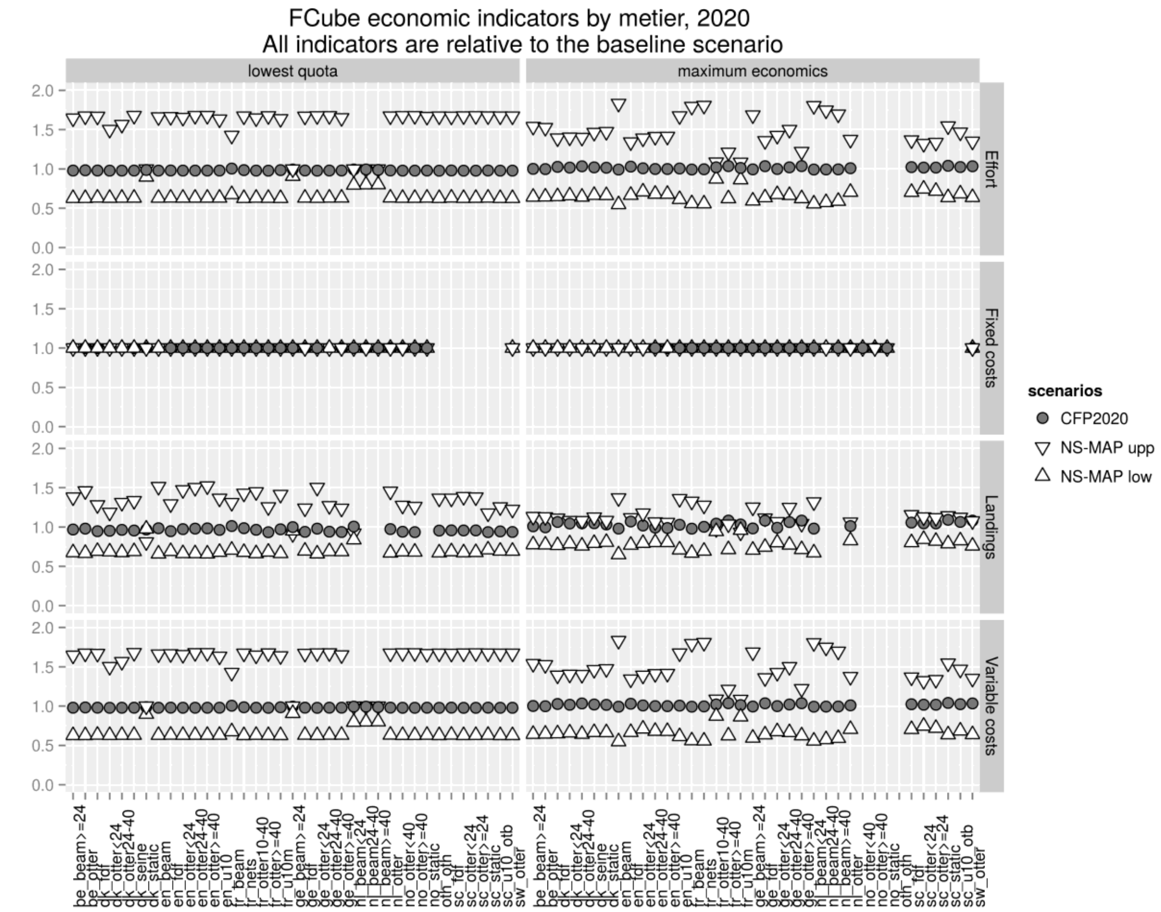


Figure 7. Comparison of economic indicators between scenarios

In comparison, the “balance “ scenario

ANNEX II – ECOPATH WITH ECOSIM DESCRIPTION

TABLE OF CONTENTS

1. MODEL DESCRIPTION AND CONDITIONING

1.1 Specification of the model used in the evaluation

The version of the North Sea Ecopath with Ecosim (EwE) model used here is based on the key-run model reported by ICES (2011), which has been calibrated by fitting to time series data from 1991-2007 and includes both fishing and environmental drivers (ICES 2011, Mackinson 2014). The catch compositions of the fleets in the key-run parameterisation were modified for this study (and in Lynam and Mackinson in review) such that the partial Fs of each fleet at the beginning of the projection year (2008) are a true representation of the data available (STECF 2007 catch data). This ensures that the modelled behaviour of the fleets in the forecast years closely reflects the present situation. While environmental data is used in calibration of the historical time fitting, they are not included in the forecast simulations from the management strategy evaluation procedure used here.

The basic structure of the model and data sources used to parameterize the food web in 1991 are described in detail in Mackinson and Daskalov (2007) and summarized in Mackinson et al. (2009) and Heymans et al (2011). The model comprises 68 functional groups including mammals (3), birds (1), fish (45), invertebrates (13), microflora (2), phytoplankton (1), discards (1), and detritus (2). Commercially important fish species are divided into juvenile and adult groups (e.g., Cod, whiting, haddock, saithe, herring), and numerous other fish groups are represented at the species level where data allow. Estimates of biomass, production, consumption rates, and diet composition for each functional group use data from various sources, the principal ones being ICES international bottom trawl surveys for fish, international benthos surveys for epifauna and infauna, the 1991 "Year of the Stomach"stomach sampling project, ICES single- and multi-species stock assessments, working group reports for seabirds, sharks, and marine mammals, specific published studies for phytoplankton, zooplankton, and microflora, and empirical models. Twelve fishing fleets are defined according to Data Collection Framework categories, with associated economic data from the 2008 Annual Economic Report (EU 2008).

2. WHAT THE MODEL DOES

A management strategy evaluation procedure is used to evaluate the effect of the alternative management strategies on the target and non-target stocks and the fisheries that capture them. Technical details of the procedure and its implement in EwE software are described in a technical report (Platts and Mackinson, 2015 (in prep)).

In this evaluation the procedure draws upon 1000 alternative plausible operating models of the North Sea ecosystem, simulating a management loop where alternative fishing mortality targets and regulatory rules can be applied (Figure A1). The procedure includes errors applied to assessment and implementation of management rules. Fishing mortality targets multiplied by the biomass of each stock are used to calculate quotas for each species that have Fmsy reference points. The quota is partitioned among fleets according to the catch compositions defined in the base year of the model, 1991. [NB: Ideally this should be the terminal year of the calibration, just prior to the forecast period, and changes are being made to implement this in the routine.]. From the 1000 ecosystem models, application of the strategies yields 213 plausible model predictions that are used to provide results.

During projections the relative effort of each fleet (a simple multiplier, made relative to an effort of 1 in the base year) is determined based on the amount of effort required to uptake the quota. In this evaluation, two regulatory components are used to determine the relative effort applied.

- **Highest Value:** The highest value quota in the fleets' portfolio is calculated at the beginning of each year based on quota and price. The effort required to ensure that the quota of the highest value species in their portfolio is fully utilised by the end of the year is spread equally across the months. If the quotas of other stocks are fulfilled during this time, they discard any fish caught above quota. In this case, quotas can be exceeded representing the flexibilities that might be implied by several mechanisms in the landing obligation (interspecies flexibility, quota swaps, banking and borrowing and de minimis exemptions).
- **Weakest stock:** The weakest stock regulation method is intended to represent a no-discards policy. The effort required to catch $1/12^{th}$ of the quota of each species is calculated each month (the timestep) and then set equal to the lowest value (the 'weakest stock'), which ensures that none of the quotas will be exceeded throughout a year. Which species is the weakest stock depends on the biomass which changes each month and therefore can change over the course of a year. The fleet has no ability to alter its catch composition (i.e. unselective), which means that the species that requires the least effort to fulfil its quota becomes the bottleneck or 'choke species' that determines the amount of effort deployed. Presently, discards are allowed for fish below minimum size if they have been specified in the basic ecopath model.

In both cases, the actual effort that is applied is subject to a constraint on the amount that it may change in any one year. The purpose of this is to represent that fishing capacity can neither increase instantaneously and unrestrained, nor would be subject to huge decreases by management aiming to minimise social impacts. In addition to this, an implementation error is applied to represent imperfect control. The values used to apply the limits and error have been set such that the resulting variability is relative effort is consistent with the variation of effort observed from 2003-2012 (STECF effort data).

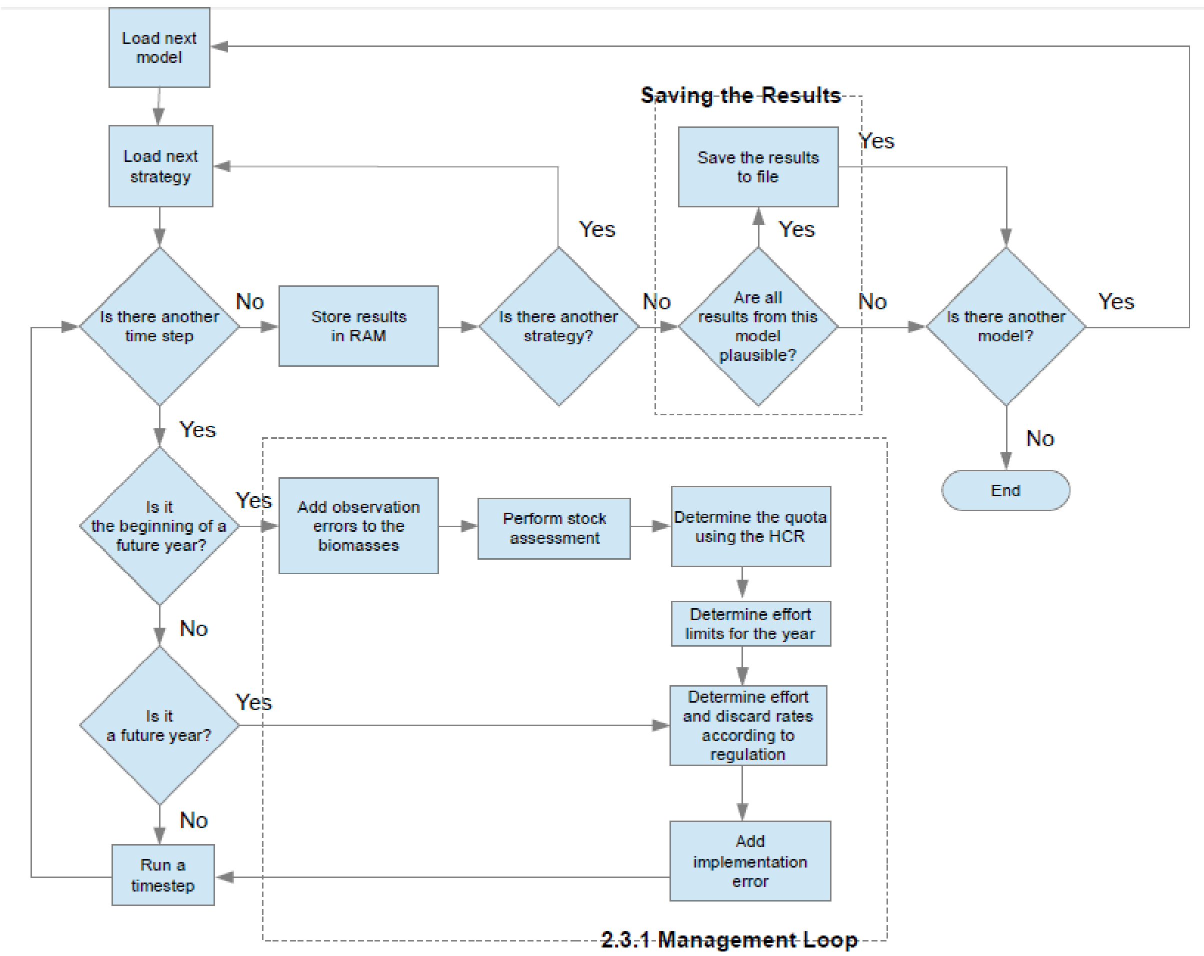


Figure A1. The model procedure.

2.1 Summary of key model aspects relevant to this application.

Does account for

- Food web interactions among fish, benthos, marine mammals, birds
- Fleet interactions – 11 fleets, including economic data (mixed fisheries)
- MSY policy
- Landing obligation policy and possibility for selective fishing
- Differences in survivability - ref to de minimis
- Conservation safeguards for target and other species
- Limits to changes in relative effort
- Uncertainty in knowledge and process
- F based on stock biomass status
- Forecast starts in 2008

Does not explicitly represent

- Interspecies quota flexibility
- Quota swaps
- Relative stability (fleets are represented as single EU fleets – based on DCF categories)
- Ability to fish selectively based on fishing time and location –avoiding choke species
- Impact of any quota uplift
- Does not (yet) provide a way to define when Fmsy must be achieved ()
- Assumes quotas based on proportion of species caught in model base year *(to be changed in future)*
- It can't guess how fleets behaviour might change

a)

3. EwE MODEL STRATEGIES

The strategies run in EwE are listed in Table A1. Each model strategy was forecast for 30 years, starting from 2008, the end of the model calibration period. Biomass projections from each of the plausible model predictions are compared against two reference points, which provide information on risk associated with each model strategy. (i) BLoss – the lowest biomass predicted in the model calibration period (1991-2007), (ii) the Bpa reference points for each species reported in ICES WKREFMSY3 (Nov 2014) (see below).

Table A1. Relationship between the STECF scenarios, their policy elements and the name of the EwE strategies. (* core elements applied to each of the STECF scenarios, $additional scenario for comparison). EwE strategies in bold are taken as being the best suited to representing the STECF scenarios.

STECF WG scenario	Conditions	EwE model strategies
Baseline CFP	- Fmsy - Landing obligation* - TAC and quotas* - Immediate move to Fmsy	**CFP_FIXEDTargetF_Highest value** CFP_FIXEDTargetF_Weakest stock
CFP2020	- Gradual move to Fmsy by 2020	***NOT currently possible in the models MSE routine***
NSMAP_highF	- High Fmsy - Safeguards	**HCR_HighF_Highest value** HCR_HighF_Weakest stock
NSMAP_lowF	- Low Fmsy - Safeguards	**HCR_LowF_Highest value** HCR_LowF_Weakest stock
NSMAP_Fmsy$	- Fmsy - Safeguards	HCR_TargetF_Highest value HCR_TargetF_Weakest stock

3.1 Table A2. Reference points for the model simulations (*not used just shown here for information)

	Fishing mortality targets			*Safeguard biomass level*	
Group name	**Fmsy**	**Low Fmsy**	**High Fmsy**	**Bpa (t) (BmsyTrigger)**	**Source**
Cod (adult)	0.2	0.13	0.33	150000	Table 10.3 WKMSYREF32014
Whiting (adult)	0.15	0.14	0.15	250000	Table 10.1 WKMSYREF32014
Haddock (adult)	0.37	0.25	0.51	88000	Table 10.3 WKMSYREF32014
Saithe (adult)	0.32	0.2	0.42	200000	Table 10.3 WKMSYREF32014
Hake	0.24	0.24	0.24	140000	http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2012/2012/hke-nrth.pdf
Norway pout	0.35	0.35	0.35	150000	http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2013/2013/nop-34%20oct.pdf
Herring (adult)	0.33	0.24	0.38	1000000	Table 10.3 WKMSYREF32014
Sprat	0.36	0.32	0.4	142000	http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2013/2013/spr-nsea_201305211647.pdf
Mackerel	0.22	0.22	0.22	2300000	http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2012/2012/mac-nea.pdf
Sandeels	0.24	0.2	0.3	510000	http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2013/2013/san-34.pdf
Plaice	0.19	0.13	0.27	230000	Table 10.3 WKMSYREF32014
Sole	0.35	0.24	0.41	35000	Table 10.3 WKMSYREF32014
Megrim	0.33	0.26	0.33	9740	Table 10.1 WKMSYREF32014
Horse mackerel*	0.06	0.04	0.06		Table 10.1 WKMSYREF32014
Nephrops*	0.12	0.09	0.12		Table 10.1 WKMSYREF32014 (mean exploitation rates)

4. OUTPUT INDICATORS (TABLE A3).

Table A3. Lists of indicators calculated for each model strategy.

Speces/ Fleet	Type	realisedF (or relative target F)	Biomass (000t)	% trials> Bloss or Blim	Landings (000t) and upper and lower quartiles	Total catch Value (mil Euro) and upper and lower quartiles	Quota uptake	Recovery time (time to >Bpa)	MSFD biodiversity and food web indicators[1]
Cod (adult)	Target species & top5 Pred	x	x	x	x		x	x	
Whiting (adult)	Target species & top5 Prey	x	x	x	x		x	x	
Haddock (adult)	Target species & top5 Prey	x	x	x	x		x	x	
Saithe (adult)	Target species & top5 Pred	x	x	x	x		x	x	
Plaice	Target species	x	x	x	x		x	x	
Sole	Target species	x	x	x	x		x	x	
Nephrops	Target species	x	x		x		x	x	
Juvenile Cod	By-catch species (discarded)	x	x		x				
Juvenile Whiting	By-catch species (discarded) & top5 Prey	x	x		x				
Gurnards	By-catch species (discarded)	x	x		x				
Dab	By-catch species (discarded) & top5 Prey	x	x		x				
Flounder	By-catch species (discarded)	x	x		x				
Witch	By-catch species (discarded)	x	x		x				
Seabirds	Threatened	x	x		x				
Spurdog	Threatened	x	x		x				
Large sharks	Threatened	x	x		x				
Skate + cuckoo ray	Threatened	x	x		x				

Speces/ Fleet	**Type**	**realisedF (or relative target F)**	**Biomass (000t)**	**% trials> Bloss or Blim**	**Landings (000t) and upper and lower quartiles**	**Total catch Value (mil Euro) and upper and lower quartiles**	**Quota uptake**	**Recovery time (time to >Bpa)**	**MSFD biodiversity and food web indicators[1]**
Catfish (Wolf-fish)	Threatened	x	x		x				
Toothed whales	Top 5 predator	x	x		x				
Seals	Top 5 predator	x	x		x				
Monkfish	Top 5 predator	x	x		x				
Juvenile Haddock	Top 5 Prey	x	x		x				
Blue whiting	Top 5 Prey	x	x	x	x				
Norway pout	Top 5 Prey & Quota species	x	x	x	x				
Sprat	Top 5 Prey & Quota species	x	x	x	x				
Sandeels	Top 5 Prey & Quota species	x	x	x	x				
Hake	Quota species	x		x					
Mackerel	Quota species	x		x					
Herring (adult)	Quota species	x		x					
Demersal trawl and seine	Fleet					x			
Beam trawl	Fleet					x			
Nephrops trawl	**Fleet**					x			
Piscivore	Trophic guild								x
Bentho-piscivore	Trophic guild								x
Benthivore	Trophic guild								x
Planktivore	Trophic guild								x

[1] Biodiversity and Food web indicators: Biomass and catch of surveyed fish & elasmobranchs, Trophic level of surveyed fish & elasmobranchs, Trophic level of catch fish & elasmobranchs, Large Species Indicator, Mean max length

5. RESULTS AND DISCUSSION

To draw out the differences in the model strategy simulations, the results are discussed in terms of how the they differ in relation to:

- Comparison of Highest value vs Weakest stock
- Comparison of fixed Fmsy vs Fmsy with safeguards where F declines linearly when the biomass of a stock falls below BmsyTrigger (Bpa)
- Comparison of LowF vs HighF (NSMAP) with Fixed Fmsy (Baseline CFP)

b)

5.1 Relative effort of selected fleets (Figure A2)

Comparison of Highest value vs Weakest stock regulations

When the *Weakest stock* regulation is applied in the model strategy, the effects of changes in in fishing mortality targets and safeguards are overwhelmed and have little to no effect. We consider this to be uninformative and of relatively little value to the analysis undertaken here.

As it is currently implemented in the model, the *Weakest stock* regulation represents an extreme situation because so long as a fishing mortality target with which to define a quota exists, the species with the smallest quota in a fleets portfolio determines the minimum effort applied by a fleet. Because the model determines quotas and automatically assigns them to fleets based on the proportion of each species caught, the model implementation assumes even those species which represent a minor part of the overall catch are, in effect, 'target species'. This is as if each 'by-catch' species has a quota and these are used to determine how much fishing effort is deployed. We have found here that these assumptions tend to result in severe decreases in fishing effort for two reasons (i) when the fishing effort is determined by a species for whom the fleet has a very minor quota, and (ii) if the biomass of one of the quota species is in decline it can result in year-on-year reductions in quota and effort until such time as the effort is low enough not to exceed the quota. We found this to occur in some of the scenarios that we tested here.

In reality not all of the species that are assigned quota for a fleet will be target species. Therefore, a smarter approach, (which we plan to develop) is where the main target species for each fleet are assigned, and only quota for the target species are used to determine the level of fishing effort in the Weakest stock regulation.

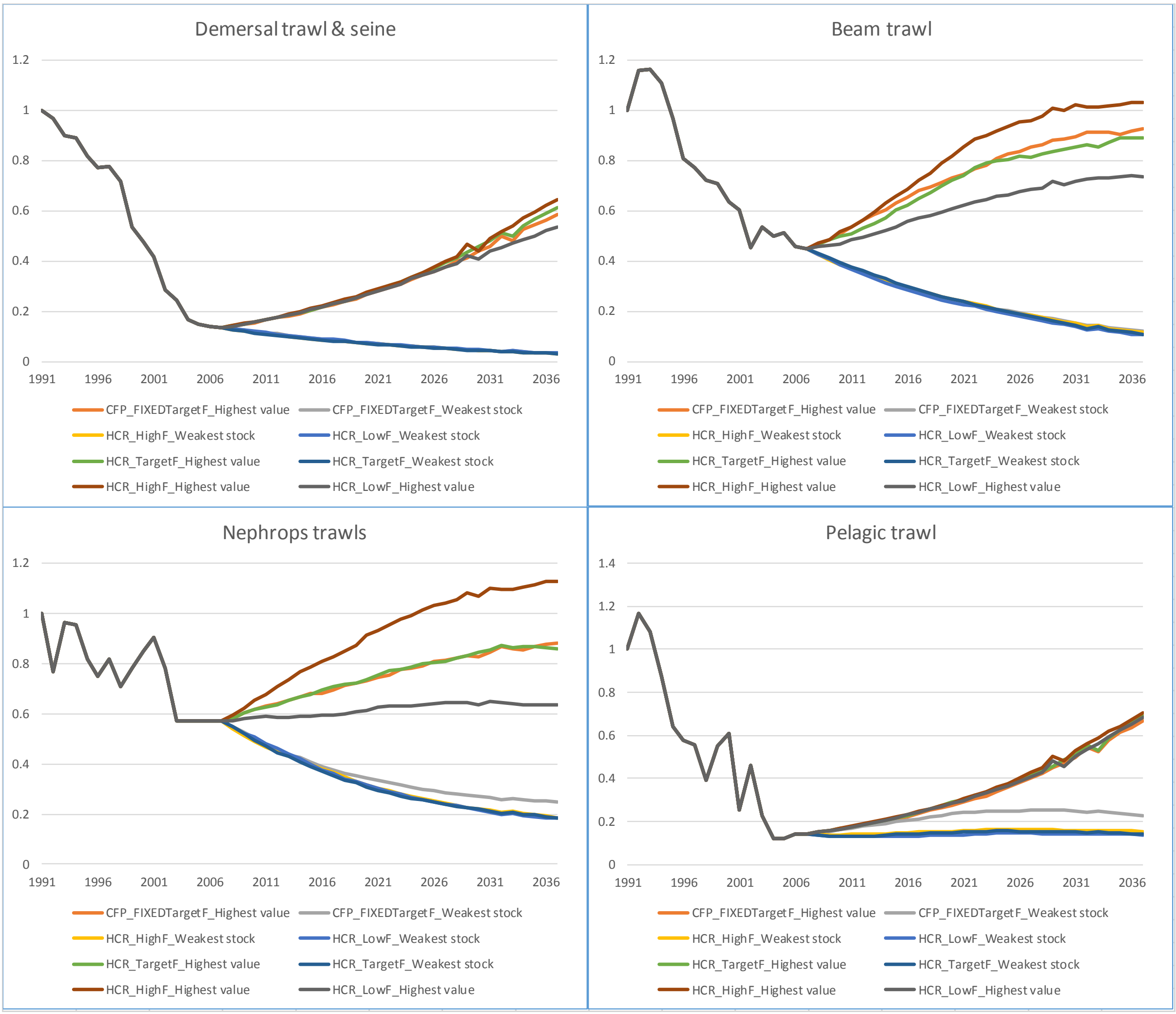
Comparison of fixed Fmsy vs Fmsy with safeguard (for highest value strategies)

The difference between the Fixed F and F determined when safeguards are included, show very little difference in the response of the relative effort of the fleets. This occurs because many of the target stocks have biomass >Bpa and thus the value of F implemented remains the same.

Comparison of Low vs High F (for highest value strategies)

Some obvious differences are apparent in the comparison between lowF and highF scenarios. Most of the fleets increase relative fishing effort at high F. One noteworthy result is the comparison between the responses of the Demersal trawl+seine and the Nephrops trawlers. The relative effort trajectories of Demersal trawl show little differences among the strategies in the first 10-15 years of the simulation. The reason for this is related to the biomass trajectories of the target stocks and impacts of safeguards kicking-in. In addition, relative effort is predicted to increase both in the highF and lowF scenarios. In contrast, relative effort of Nephrops trawlers remains about level under the lowF scenario, but shows clear differences among the strategies from the beginning of the forecast period and a levelling off in later years.

Less obvious is the result for ‘Gears using hooks’, where the relative effort is higher under the lowF scenario when compared to the highF scenario. This is a result of multispecies interactions affecting the biomass of a high value species caught by that gear.



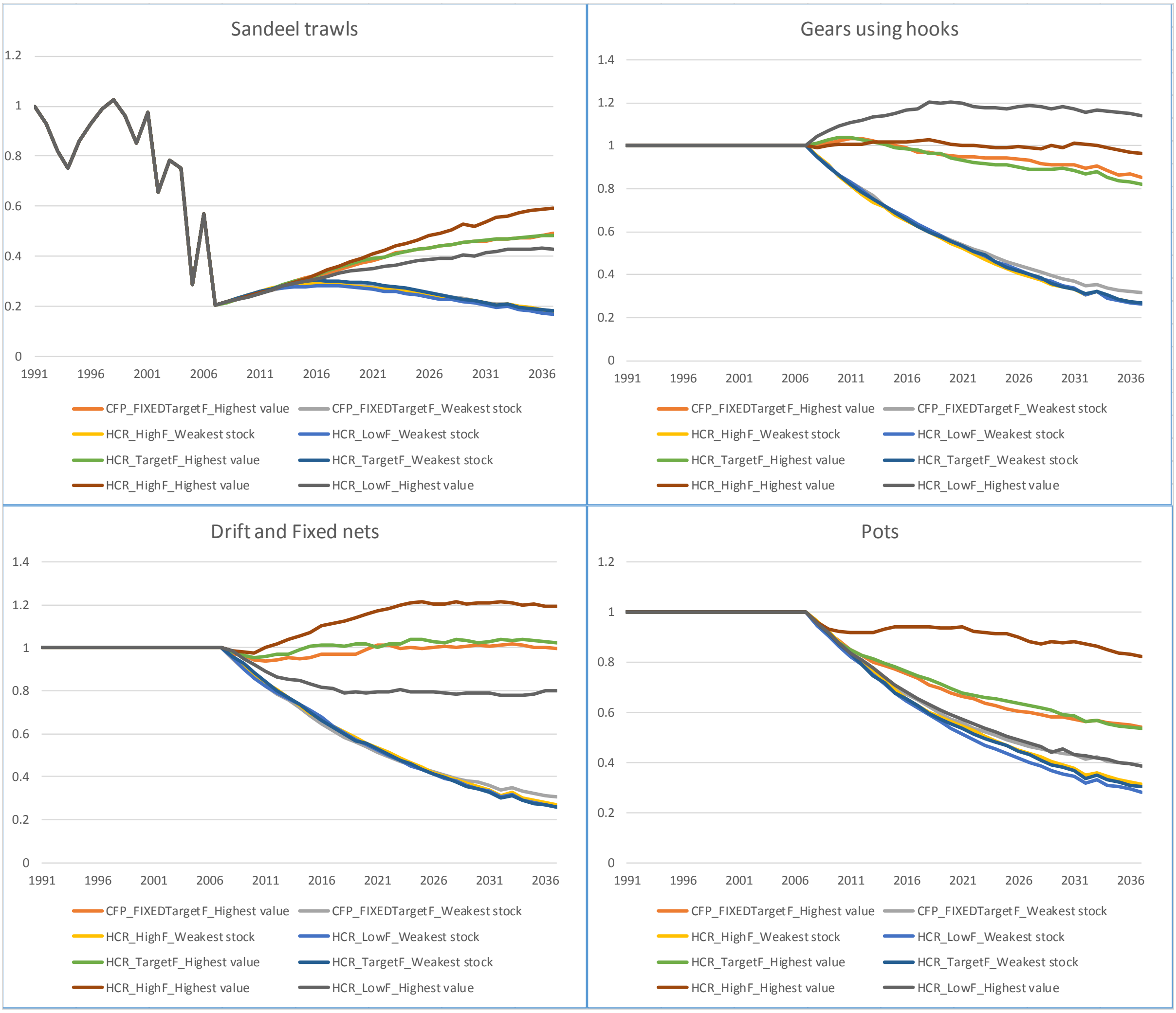


Figure A2. Relative effort of modelled fleets

5.2 Fishing mortality, Biomass, Landings, Quota utilisation and Values

Note: During close scrutiny of the results an error was detected in the fishing mortality applied to some functional groups at the beginning of the forecast period. It relates specifically to those groups that use fishing mortality time series from stock assessment as a direct input in the hindcast, rather than and F derived from changes in relative fishing effort and F in the base year of the model – as is applied to species. At the beginning of the forecast period the MSE routine uses the relative effort to estimate the F on each species, which means for some species there is a mismatch between the F at the end of the hindcast and the beginning of the forecast (i.e a 'jump' over one year).

The effects of this are visible in the fbar plots for the six main species considered here, where it can be noticed that the values at the beginning are different (mostly lower) than those at the end of the forecast period (Table A4).

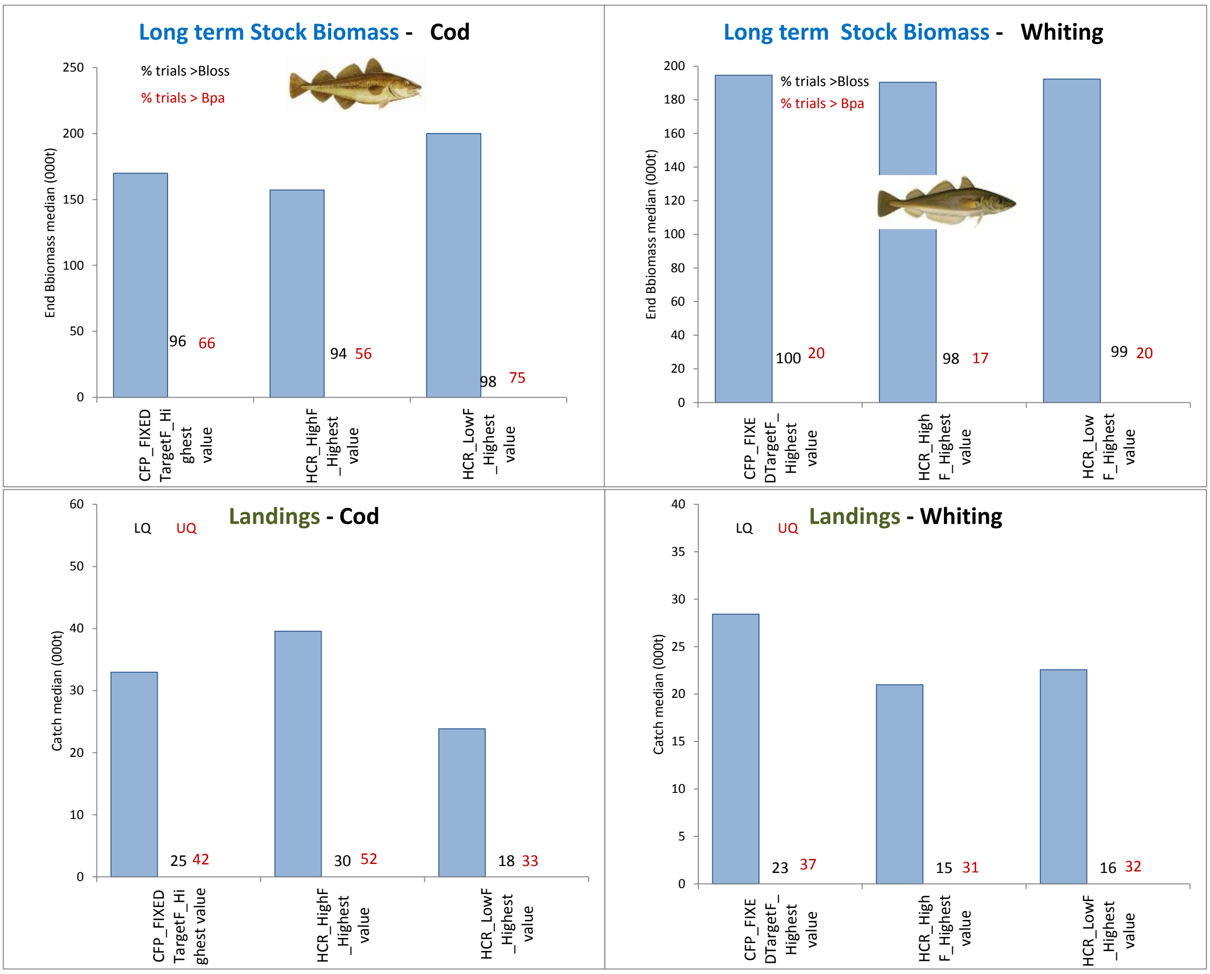
Although this is not wholly adequate and needs to be resolved because of the need (in this case) to focus on species that have stock assessments, the implications are quite minimal, with the effects being restricted to the dynamics in the early years of the forecasts. The results from the longer term strategic view of the simulations are still relevant because fishing rates are modified in accordance with the F rates defined by alternative fishing strategies (either as fixed F values or dependent on the biomass of target stocks).

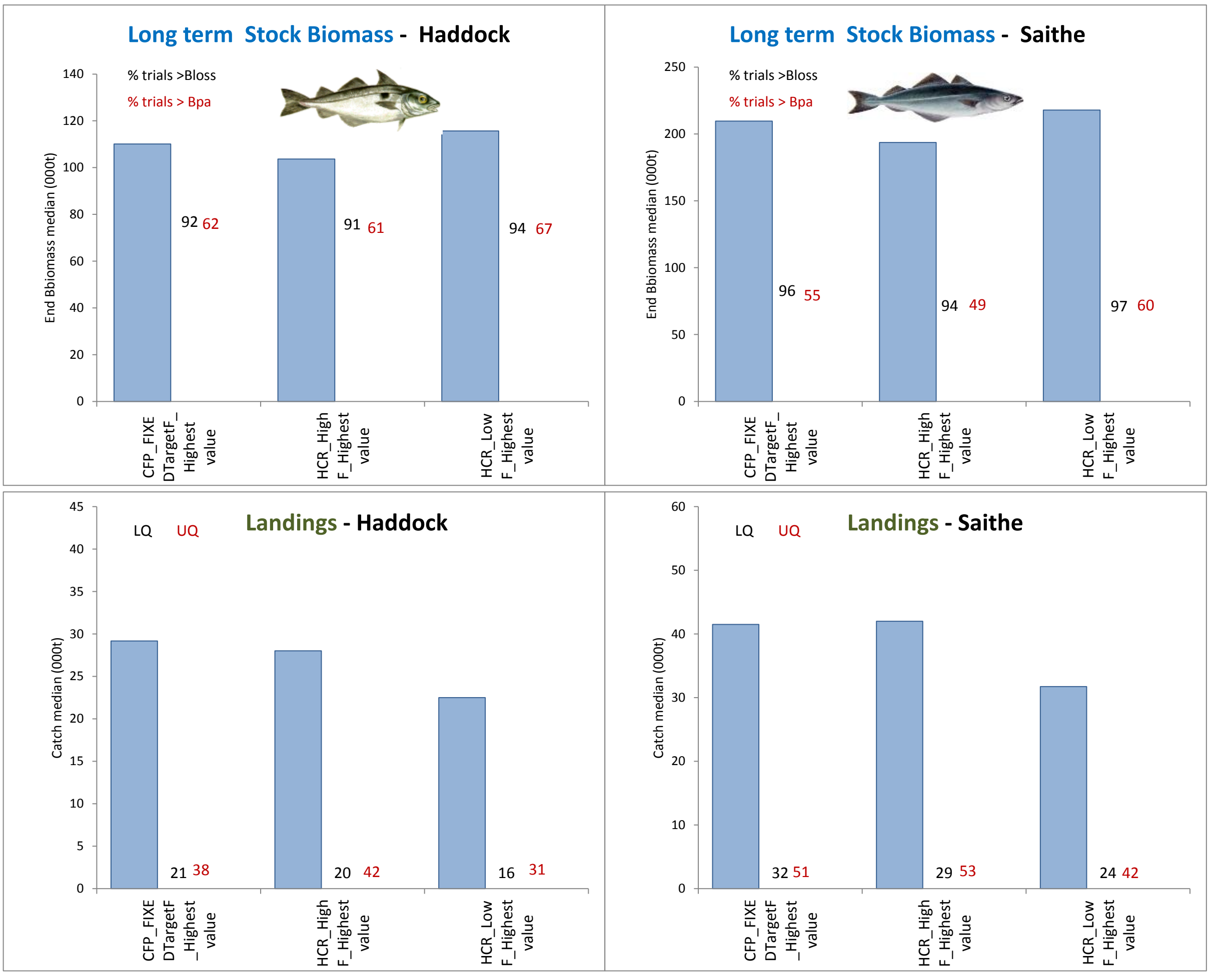
Table A4. Comparison of F values in the hindcast and start of the forecast periods for the top 6 species of interest.

	F at end of hindcast (2007)	Median F at beginning of forecast (2008) [CFP_FIXEDTargetF_Highest value]
Cod (adult)	0.64	0.13
Haddock (adult)	0.42	0.06
Saithe (adult)	0.25	0.04
Sole	0.43	0.25
Whiting (adult)	0.44	0.13
Plaice	0.39	0.25

Comparison of Fixed Fmsy (Baseline CFP) with LowF vs HighF (NSMAP)

Biomass for the top 6 fish species is higher in the lowF scenarios than Fmsy and highF scenarios. (Figure A3). However, an important result is that Nephrops biomass is highest under the highF scenarios. This is predicted as a result of reduced predation pressure from stocks whose biomass declines under highF. Landings of each species are all lower under the lowF scenario, as are landed value of the principal fleets (Figure A4).




Long term Stock Biomass - Haddock
% trials >Bloss
% trials > Bpa
End Bbiomass median (000t)
140
120
100
80
60
40
20
0
92 62
91 61
94 67
CFP_FIXEDTargetF_Highest value
HCR_High F_Highest value
HCR_Low F_Highest value
Long term Stock Biomass - Saithe
% trials >Bloss
% trials > Bpa
End Bbiomass median (000t)
250
200
150
100
50
0
96 55
94 49
97 60
CFP_FIXEDTargetF_Highest value
HCR_High F_Highest value
HCR_Low F_Highest value
Landings - Haddock
LQ UQ
Catch median (000t)
45
40
35
30
25
20
15
10
5
0
21 38
20 42
16 31
CFP_FIXEDTargetF_Highest value
HCR_High F_Highest value
HCR_Low F_Highest value
Landings - Saithe
LQ UQ
Catch median (000t)
60
50
40
30
20
10
0
32 51
29 53
24 42
CFP_FIXEDTargetF_Highest value
HCR_High F_Highest value
HCR_Low F_Highest value

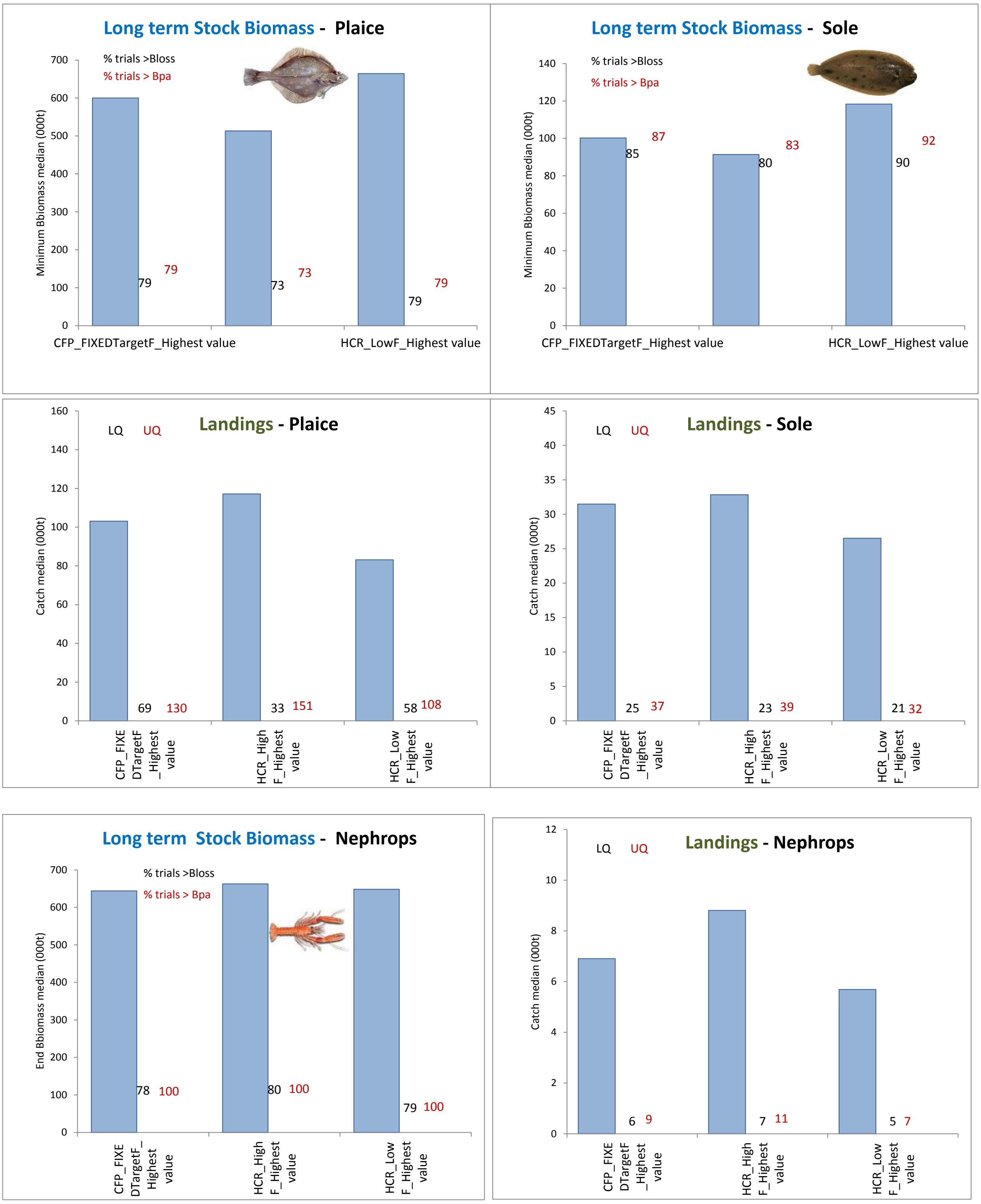


Figure A3. Long term (after 30 years) Biomass and Landings for top 6 fish and Nephrops. Median biomass and landings from 213 plausible predictions of the model. The percentage of trials whose biomass is >BLoss and Bpa provides information on risk associated with each model strategy. Landing plots give upper and lower quartiles.

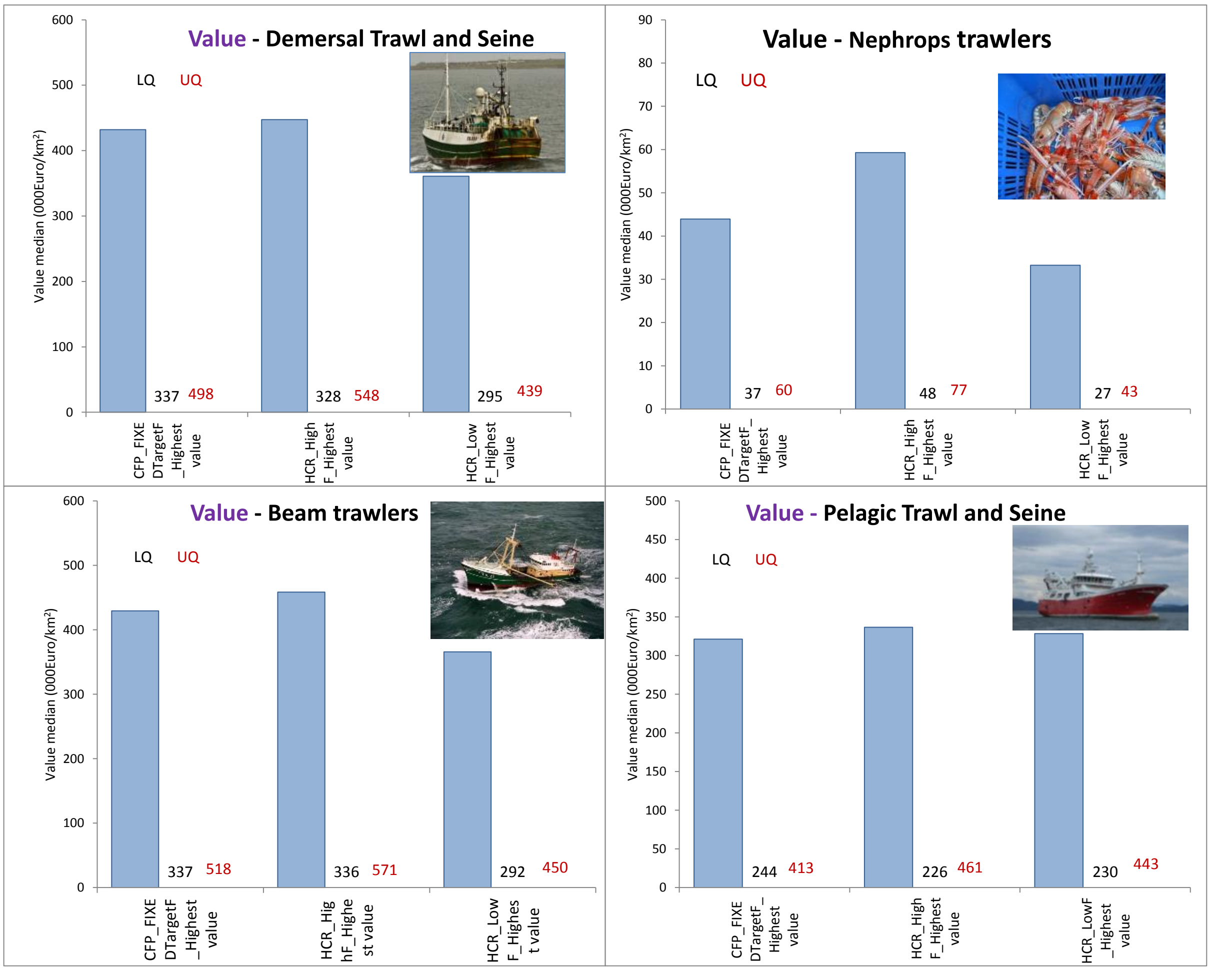
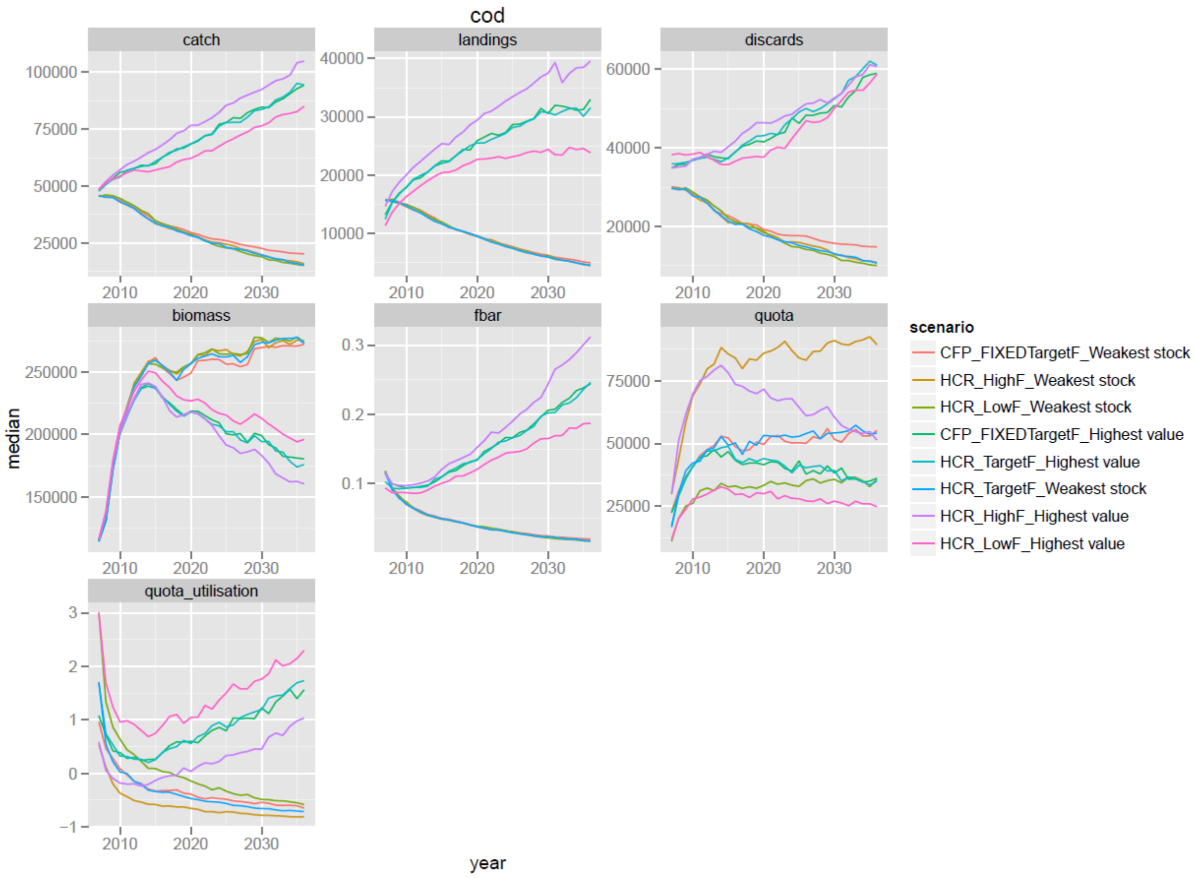


Figure A4. Long term (after 30 years) landed values for 4 selected fleets. Median values from 213 plausible predictions of the model, along with lower and upper quartiles.

Summary plots of the trajectories of key variable for the top 6 species are shown in Figure A5.



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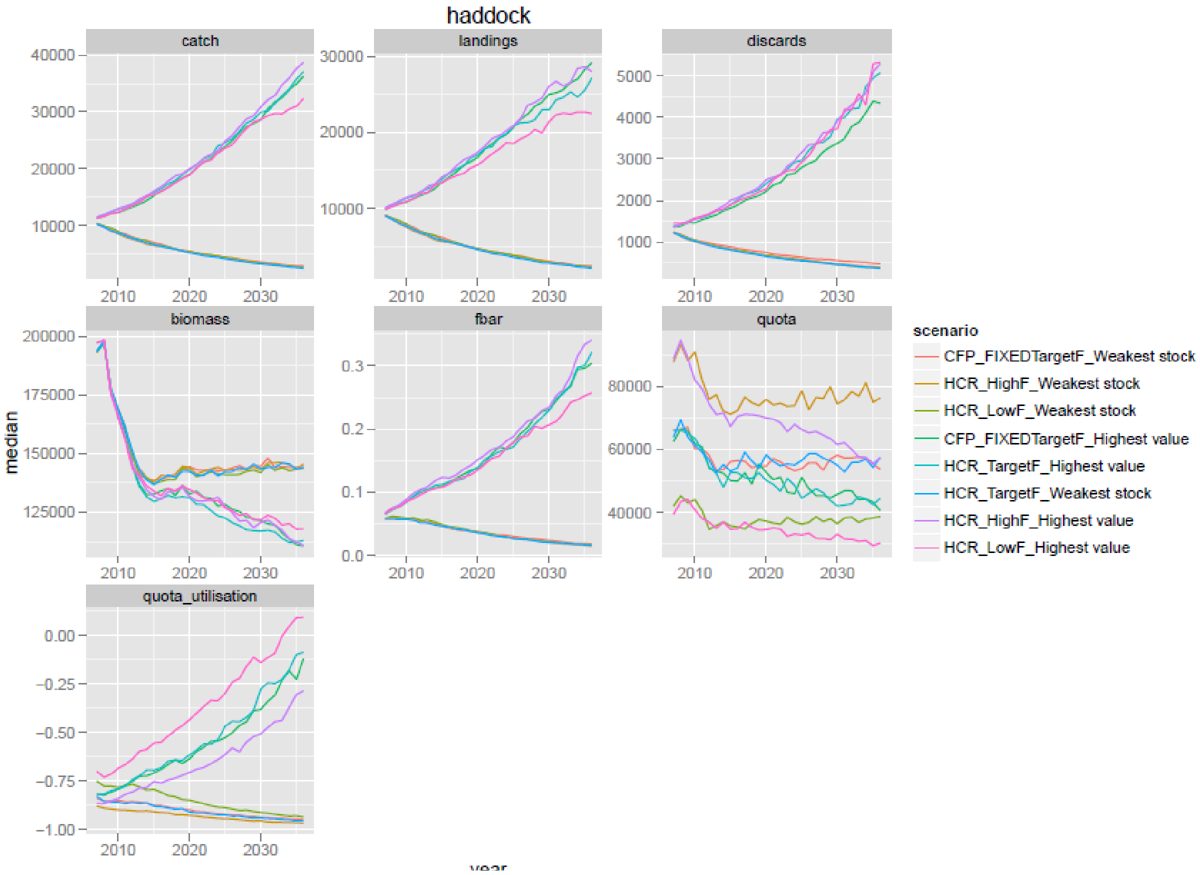
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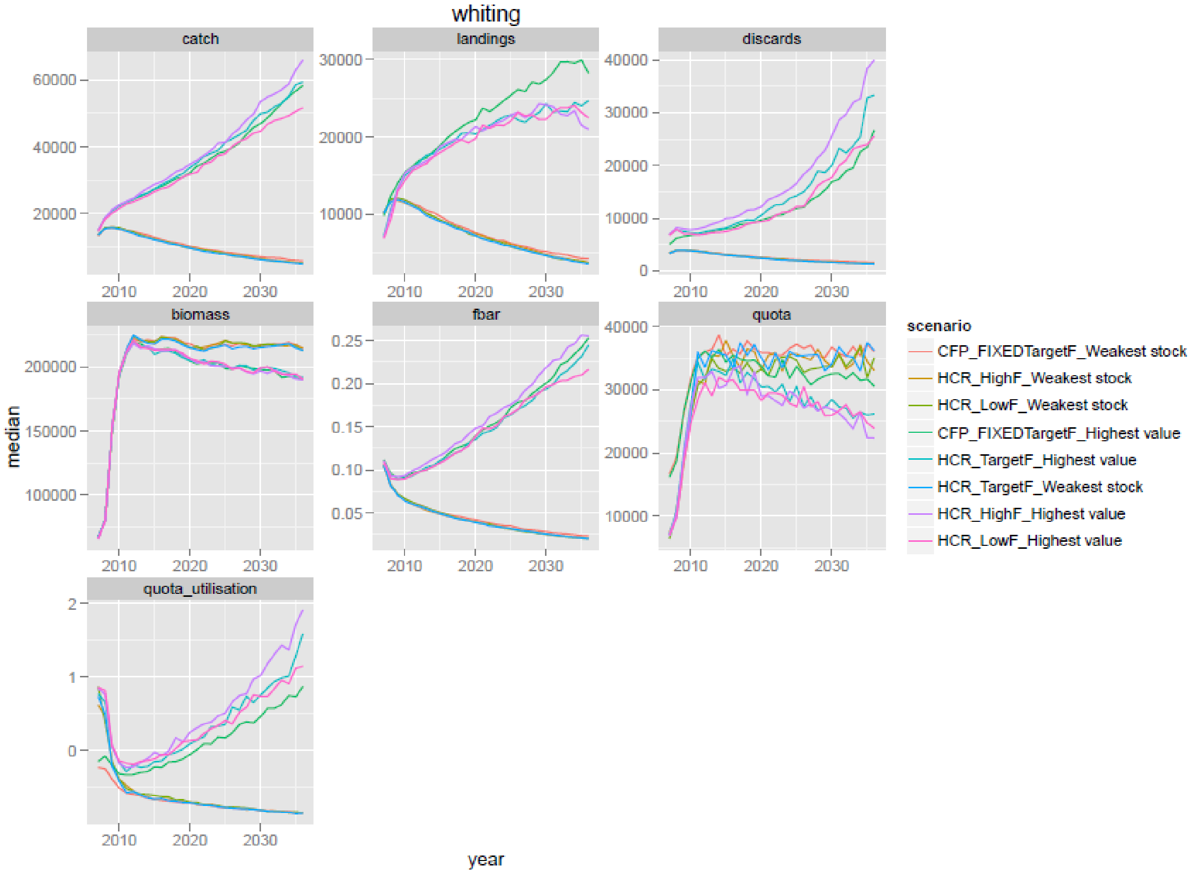
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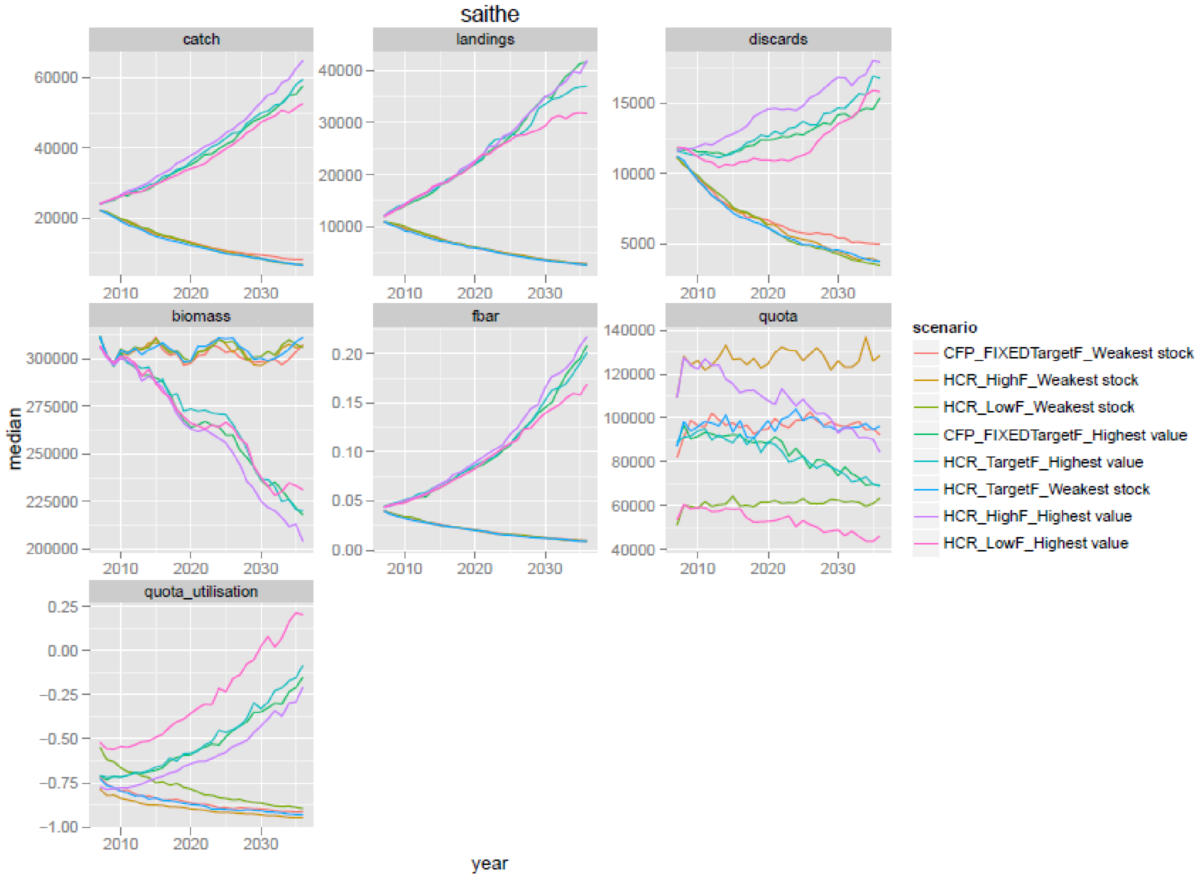
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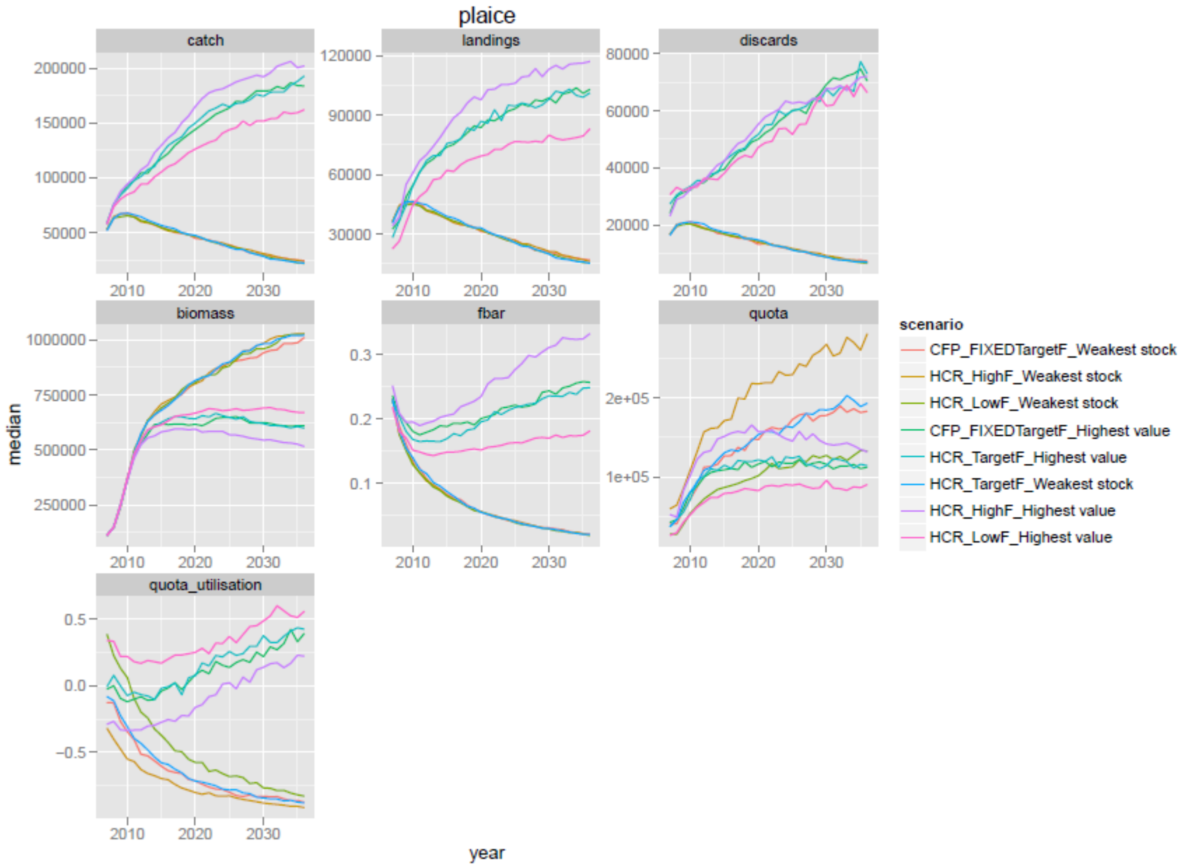
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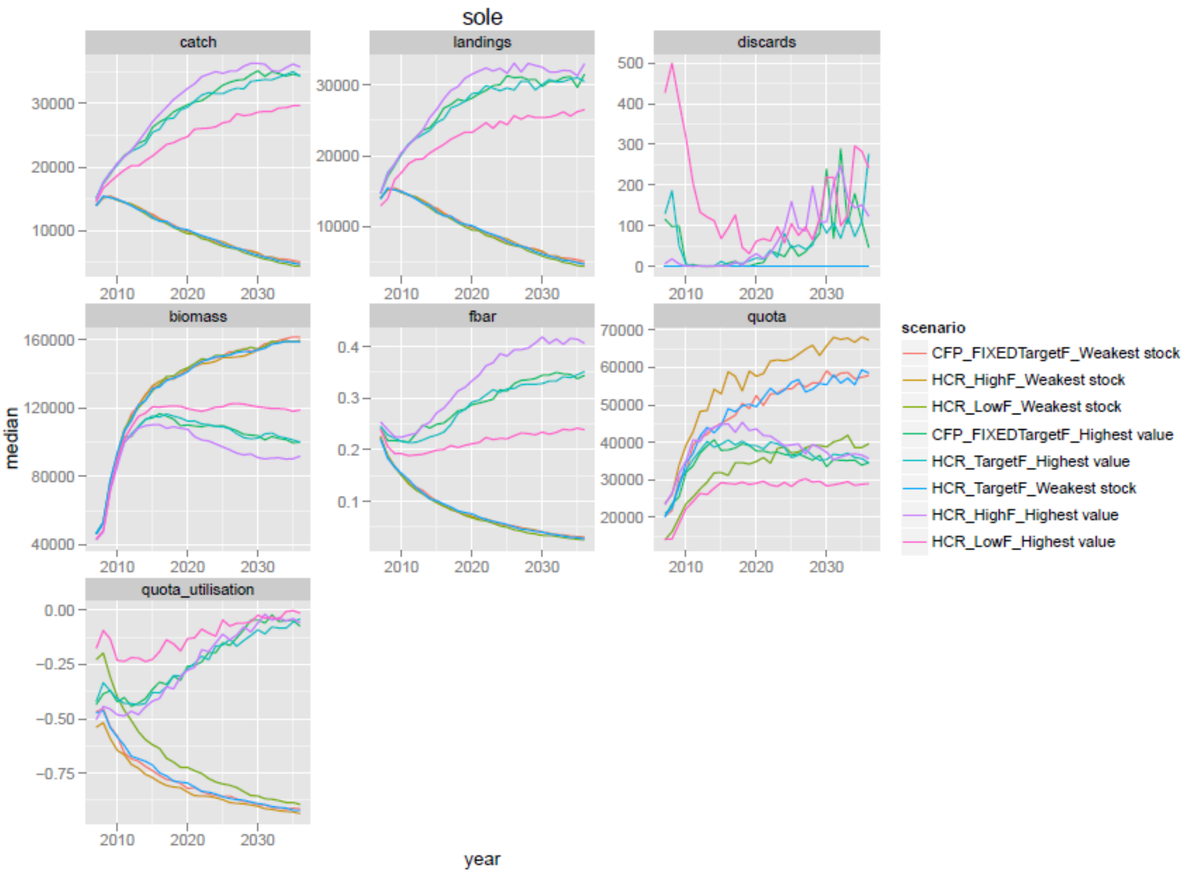

Figure A5. Summary trajectories of key variables for cod, haddock, whiting, saithe, plaice, sole [see note at beginning of section re Fbar plots].

5.3 Bycatch, Prey, Predators and Threatened species (Figure A6-A9)

Comparison of all strategies

Several of the species listed as by-catch and top 5 prey are shown to be insensitive to the differences in the policy options. This is because the fishing mortality accounts for a small part of the total mortality and because parameters in the model mean that their dynamics are more strongly determined by bottom-up factors (food availability) rather than top-down (predation and fishing) effects.

The effects of the fishing strategies are much more evident for higher predators – including those grouped as top 5 predators of the target species, and those in the 'threatened' group. With the exception of Seabirds and Skate+cuckoo ray, which decline, the Weakest stock scenarios result in initial biomass increases for the species shown. The decline in Seabird biomass is linked directly with the reduction in discards. Effects of different targets for F are seen to be quite variable for higher predators, reflecting responses that are both direct (when caught) and indirect (when changes in prey abundance influence them).

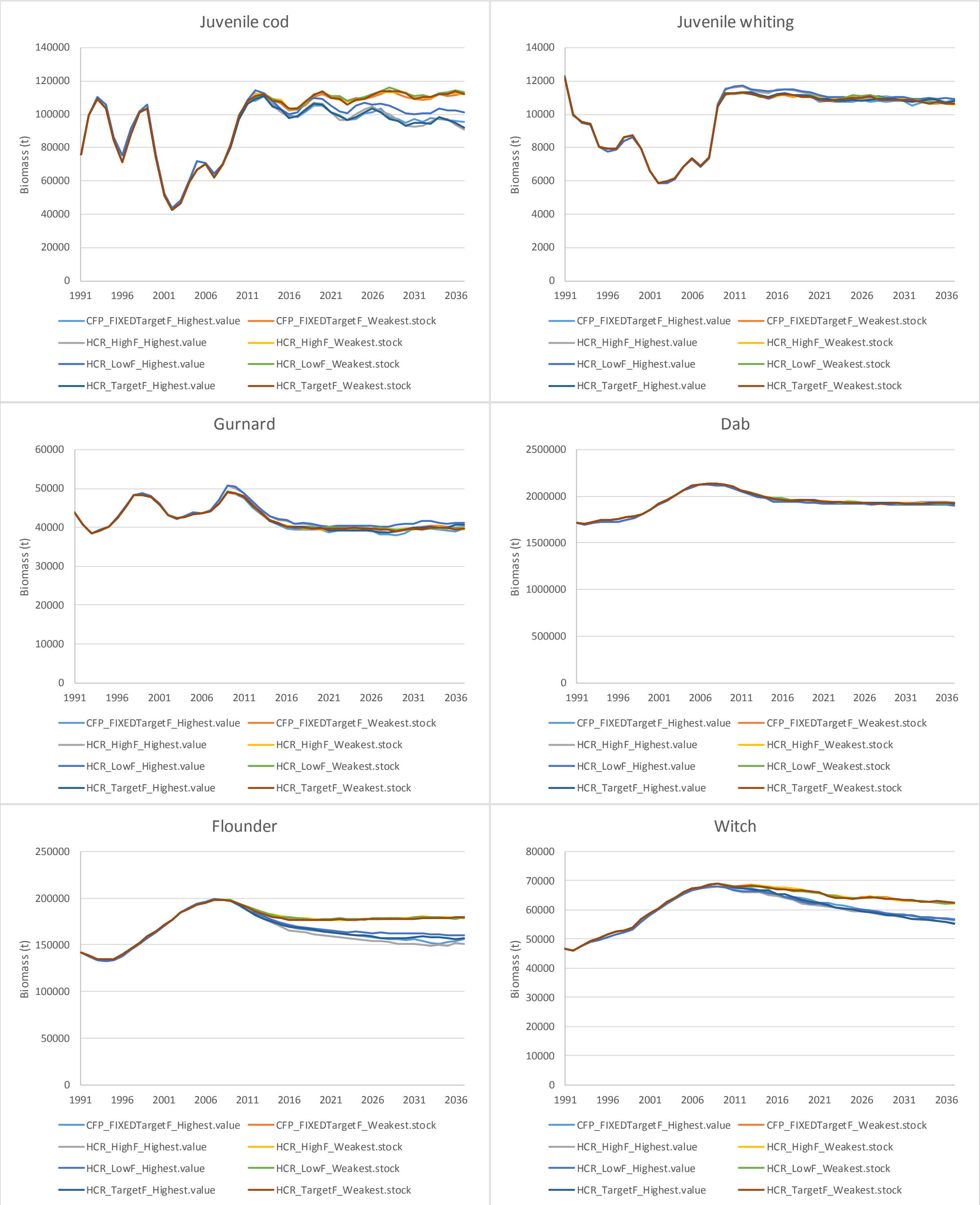

Figure A6. By-catch

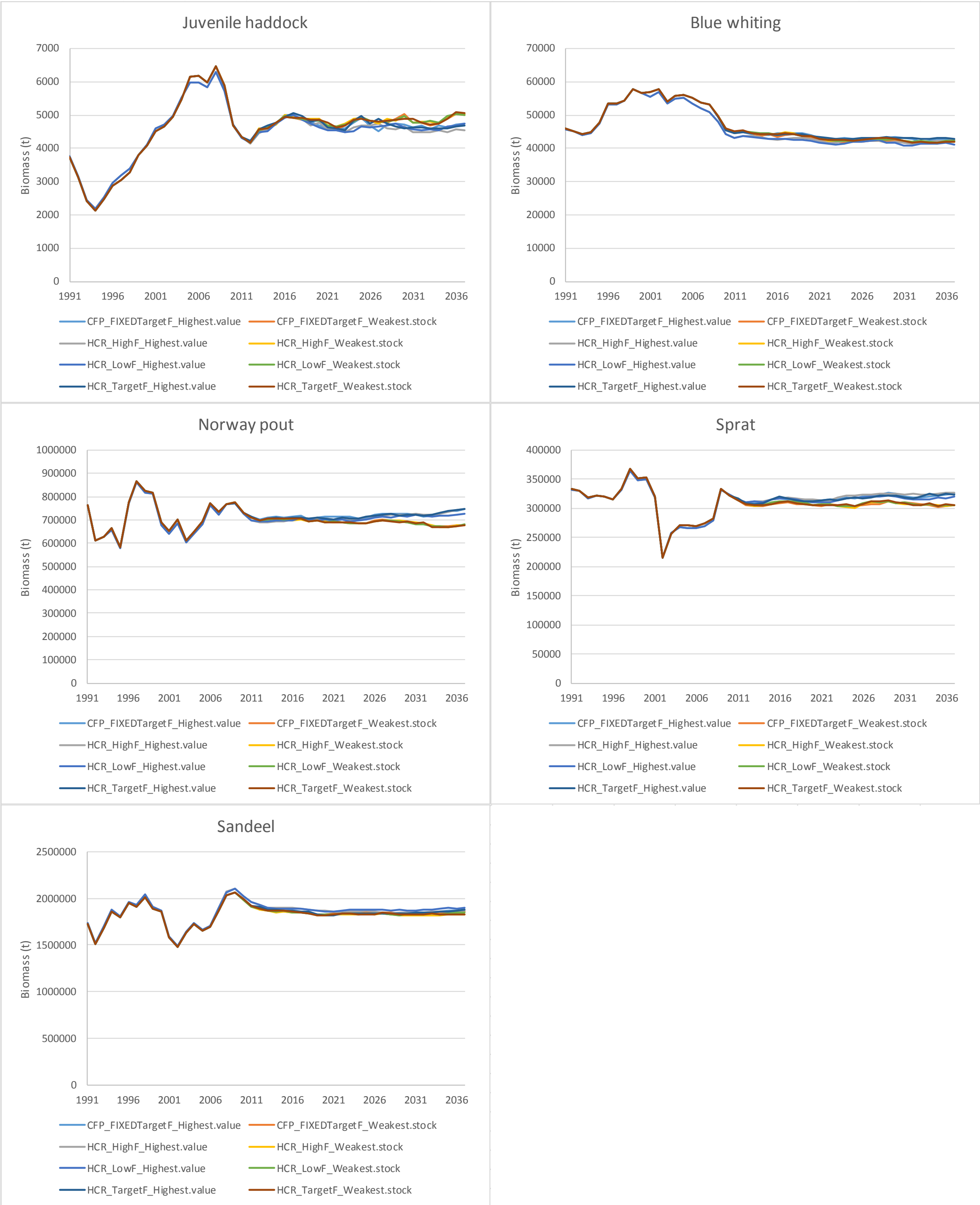

Figure A7. Top 5 Prey

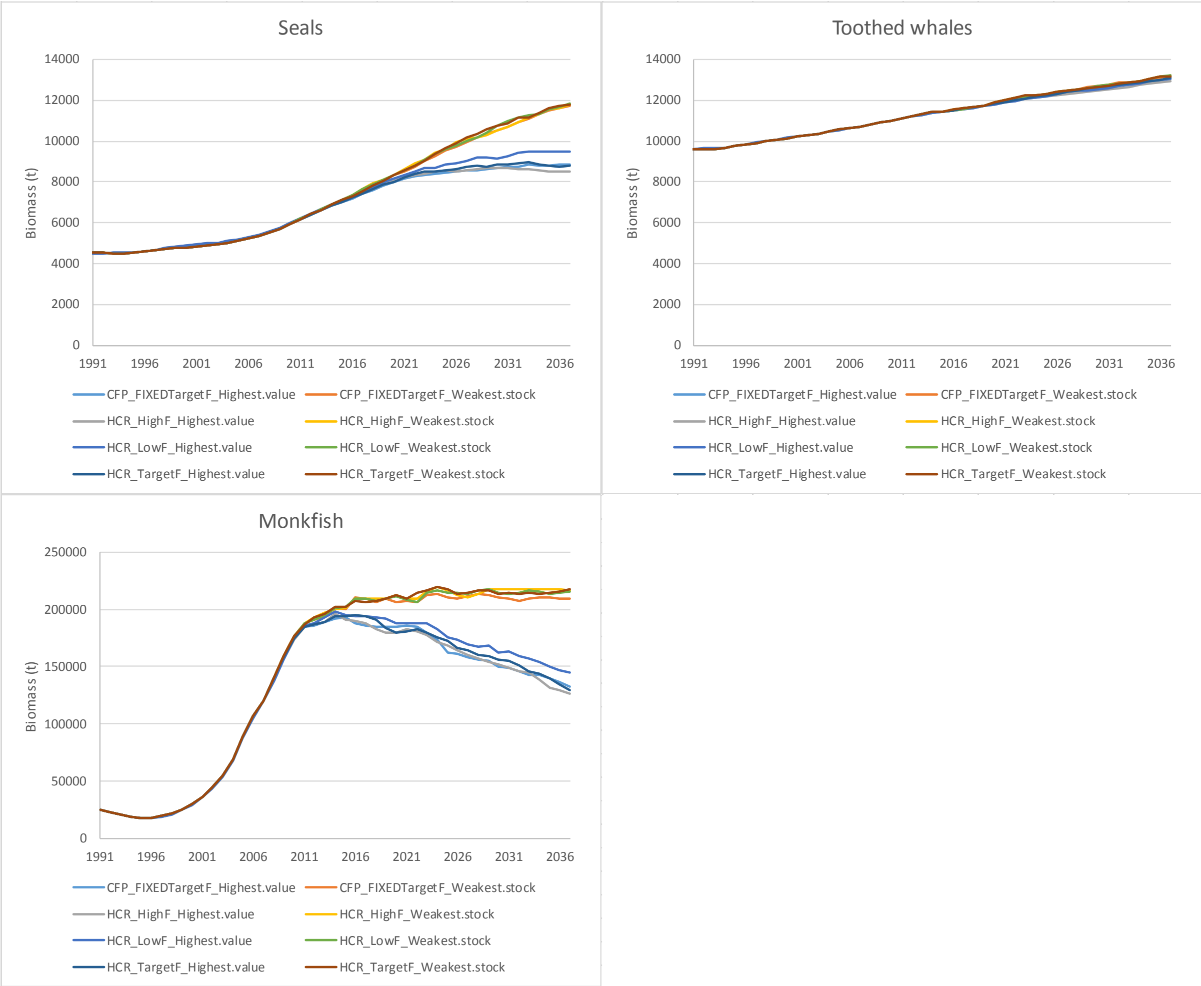

Figure A8. Top 5 Predators

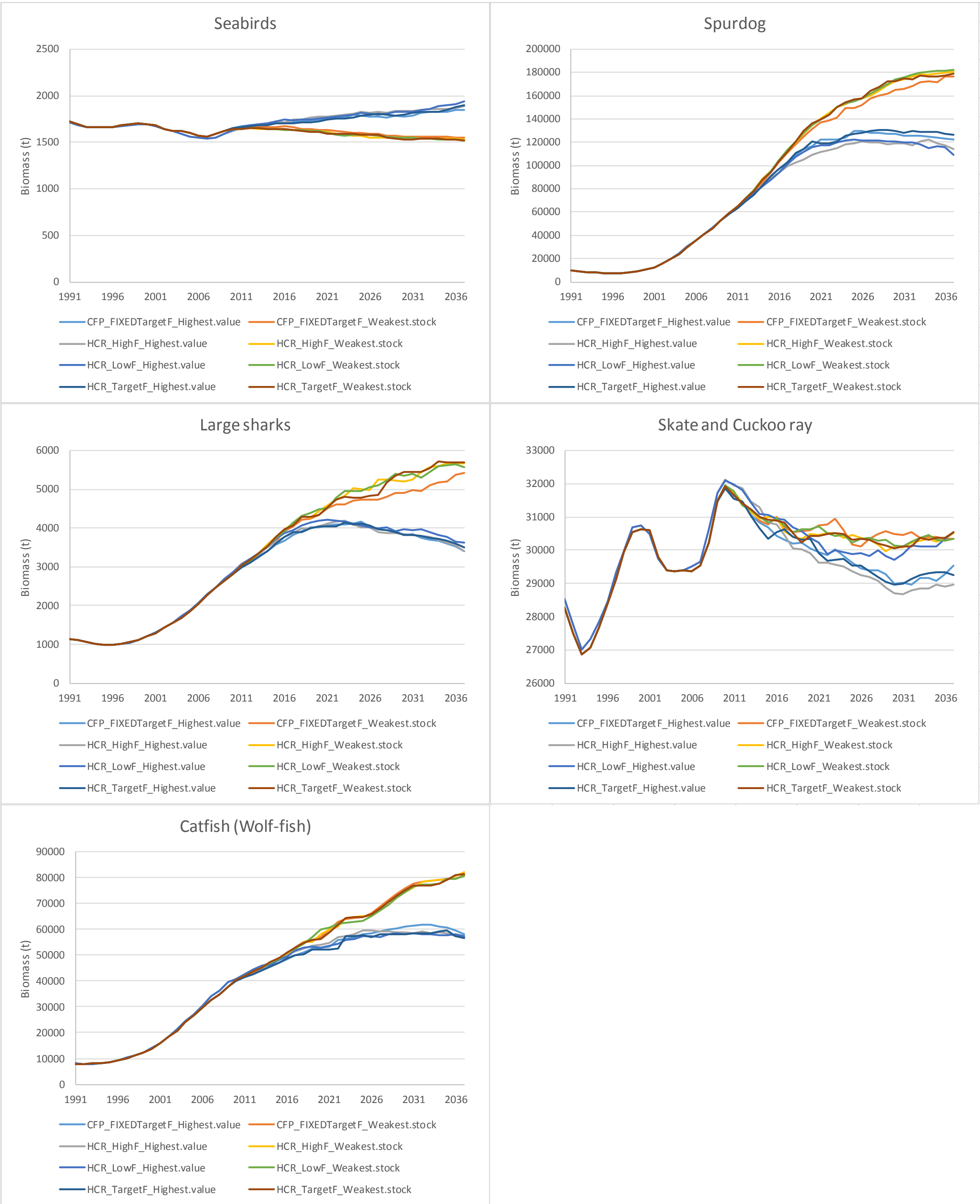

Figure A9. Threatened groups

5.4 Biodiversity and food web indicators

Comparison of all strategies

Important features that emerge from comparison of ecosystem indicators (Figure A10-A12) include (i) the drastic reduction of fishing under the Weakest stock scenarios lead to increases total biomass of surveyed species. But while piscivorous and benthic biomass increase, there are declines in other groups that are eaten by them. (i.e the contrary responses of the trophic guilds reveals trophic interactions) (ii) under highest value scenarios the effects on higher trophic level species are are more apparent than the effects on lower trophic level species (i.e cascading up the food chain). (iii) LowF scenarios have more positive effects on species biomass than the Fmsy and HighF scenarios.

Increases in biomass of large predatory fish predicted by the weakest quota scenario, are reflected in changes in the size composition of the fish (+elasmobranch) community (Figure A12). Mean maximum length and the Large Species Index are both predicted to increase. Under the maximum economics (Highest value) scenario, similar increases occur in the first 10 years of the forecast. This corresponds to a period of increasing biomasses of some large predatory fish resulting from decreases in fishing mortality. The latter half of the forecast predicts a slight decline, which appears to be as a result of increased abundance of marine mammal predators.

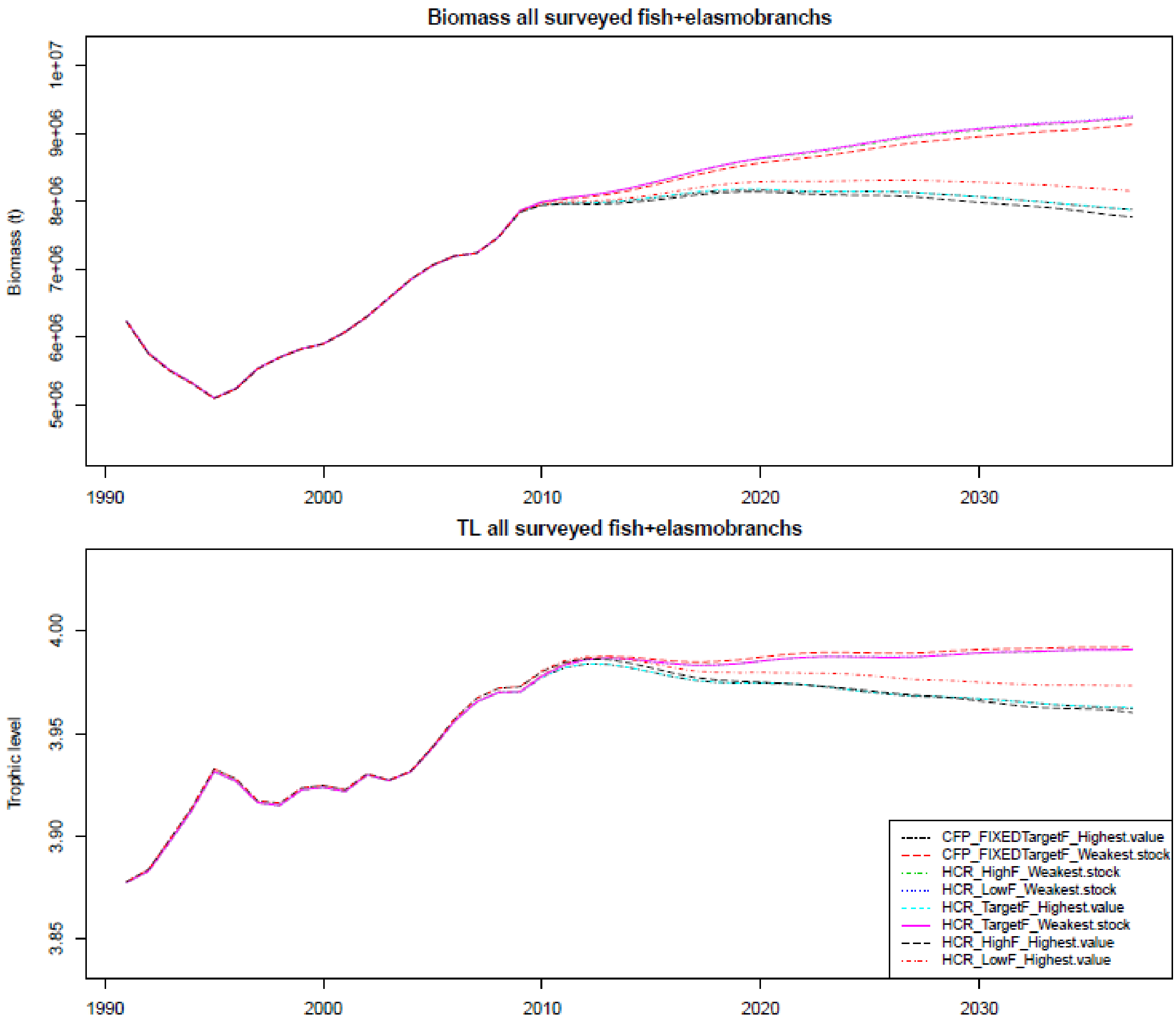

Figure A10. Changes in biomass and Trophic Level (TL) of all surveyed fish (those listed in IBTS surveys)

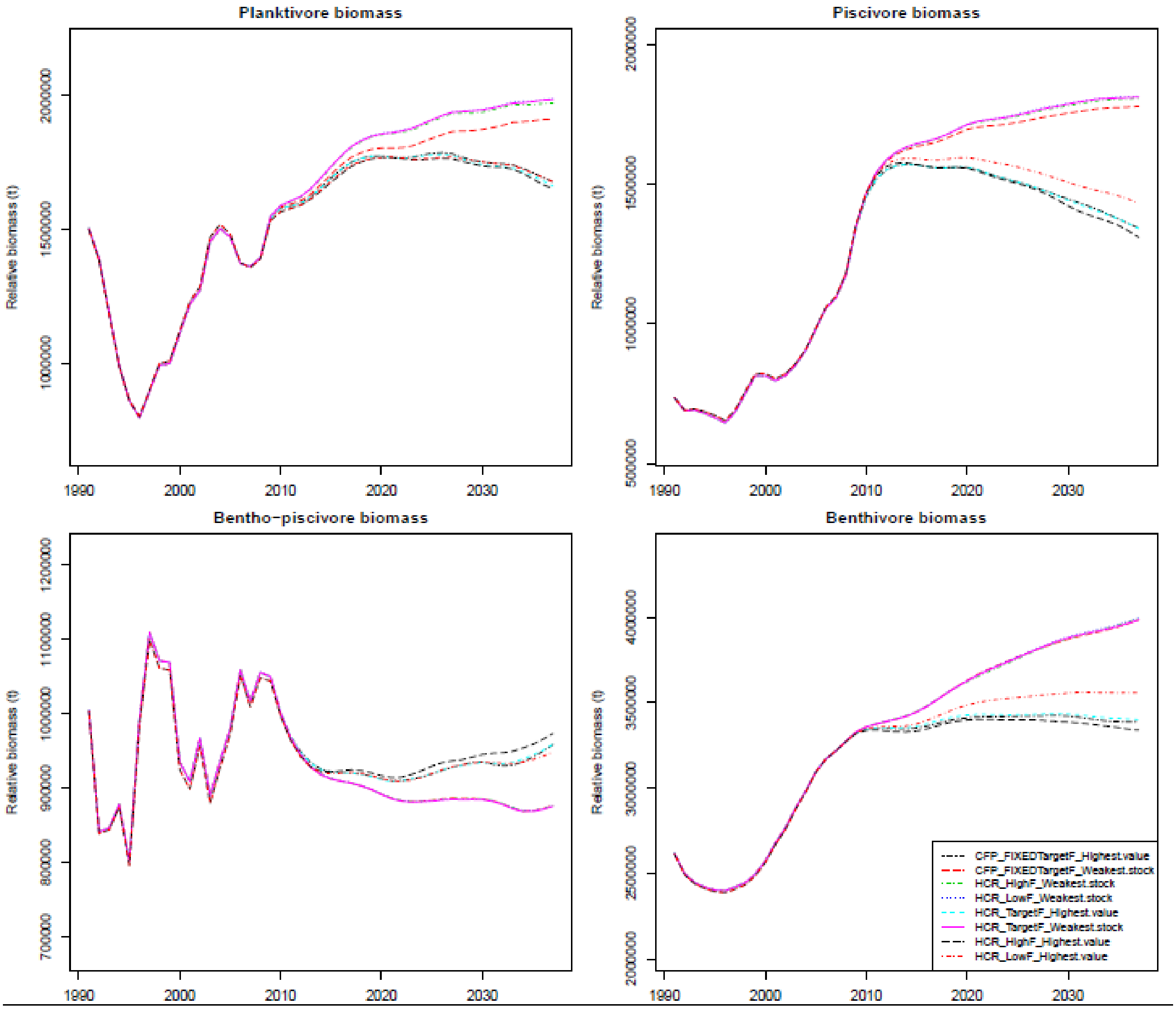

Figure A11. Biomass predictions of different trophic guilds.

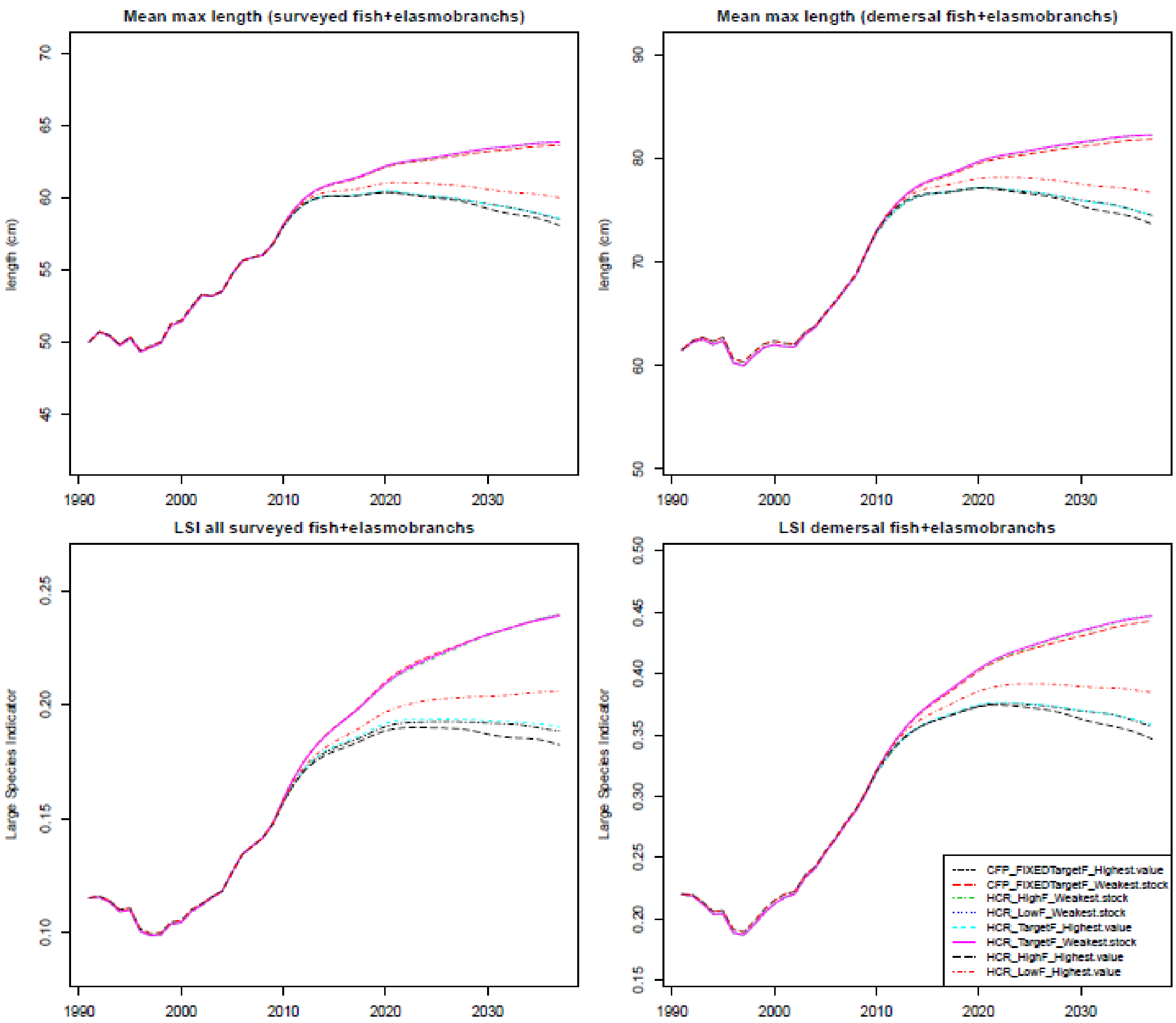

Figure A12. Size-based community indicators – Large Species Index and Mean Maximum Length. Median value from all plausible model scenarios are shown.

6. Summary of main findings

- The effects of the models regulatory component of the strategy far outweigh effects from changes in Fmsy ranges. But, the Weakest stock regulation in the model is not considered a realistic scenario.
- Fixedtargets or Safeguards – show little contrast in the response
- Nephrops, Seabirds, Skate+Cuckoo rays groups in the model are shown to have contrary responses to the strategies than other species:
  - Nephrops increases at higher fishing rates of its predators, and in the long-term responds oppositely to the strategies.
  - Seabirds decline when discarding no longer occurs
  - Skate and Cuckoo ray show declines in all the scenarios but the effects caused by direct (fishing) and indirect (pred-prey) responses
- Ecosystem impacts most evident for higher predators, with many ‘prey’ species less sensitive to changes in fishing strategy, even over longer time periods.

- Predators of the fished target species are visibly affected – including threatened and vulnerable species of conservation interest.
- The consideration of multispecies interactions in the model are an important contribution to understanding the possible effects of a NSMAP, showing how species interactions may ‘compromise’ ability to hit specified time frames for Biomass targets.

7. RELEVANT REFERENCES

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ANNEX III – SIMFISH DESCRIPTION

III.1 Model description (from Bartelings et al. submitted)

SIMFISH is a spatially explicit bio-economic model developed in EU projects (VECTORS, COEXIST, SOCIOEC, MYFISH) based on the model FishRent (Salz et al. 2010). The model is structured in modules (Figure 1).

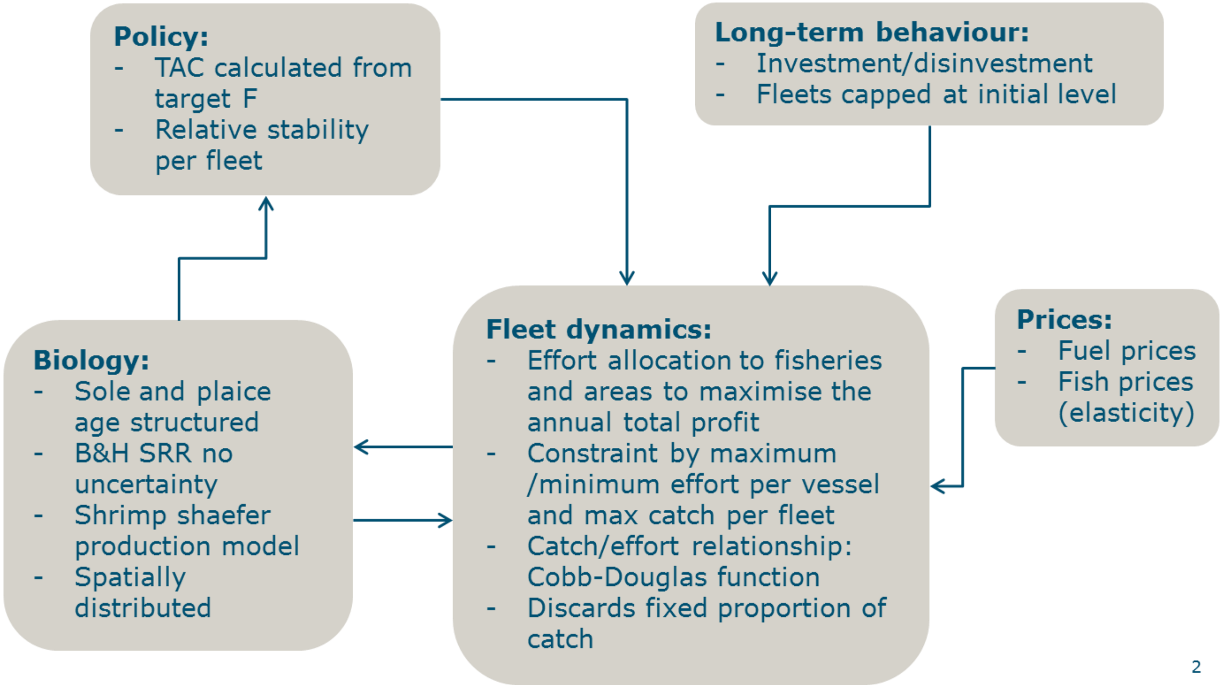


Figure 1 SIMFISH structure

Fleet dynamics

The model allocates the effort spent by fleet *j*, in fishery *k*, in area *n*, within a year in order to maximise the overall net profit. Fishing effort can be allocated to different fisheries (single and multi-species fisheries). While effort spent in a multi-species fishery results in several target species caught together, only one target species is caught in a single species fishery. Fleets can participate in both single and multi-species type of fisheries.

Profit *(PrF)* is defined as the total value of the landings (*Rev)* minus variable and fixed costs. Variable costs depend on either effort spent or on obtained revenue whereas fixed costs only depend on the size of the fishing fleets. In the model the variable costs are separated in three categories: fuel cost (FuC), crew cost (CrC), and other variable costs (VaC) and fixed costs in two categories: fixed vessel cost (FxC) and capital costs (CaC). The total profit is calculated as a sum of the profit of all fleets *j*.

Objective: $\boldsymbol{Maximize} \sum_j \boldsymbol{PrF_j} = \sum_j \left(\boldsymbol{Rev_j} - \boldsymbol{FuC_j} - \boldsymbol{CrC_j} - \boldsymbol{VaC_j} - \boldsymbol{FxC_j} - \boldsymbol{CaC_j}\right)$

Yearly revenue of a fleet *j* is calculated as the sum of the value of landings (*Land*) of the target species *i* multiplied by a factor accounting for the value of landings of other species and other income (OtSpR). The revenue of target species is calculated using the weight of landings and price at age *c*. Other species are considered by-catch and their value is assumed linearly related to the value of landings of the target species.

$$Rev_j = \left(1 + OtSpR_j\right) \cdot \sum_{i,c} \left[Land_{i,j,c} \cdot price_{i,j,c}^{fish}\right]$$

Costs are calculated per fleet on an annual basis. Fuel costs calculation is shown in Eq. 7. Fuel costs are the product of effort in days at sea (including fishing and steaming time), fuel consumption per unit of effort for fishery k ($FuC_{j,k}^{0}$) and the fuel price ($price_j^{fuel}$).

$$FuC_j = \sum_{k,n} \left[FuC_{j,k}^{0} \cdot Eff_{j,k,n} \cdot price_j^{fuel}\right]$$

Crew costs are calculated as a share CrC_j^0 of the revenue minus the fuel costs (Eq. 8). This structure is chosen to resemble how crew wages are determined in the fleets considered. In the Netherlands, for example the crew get a small fixed wage and a larger variable wage proportional to revenue of fishing trips from which fuel costs are deducted. $CrC_j = CrC_j^0 * (Rev_j - FuC_j)$

The other variable costs include costs of landing, auction and harbour fees, and are determined as a fixed share VaC_j^0 of the gross revenue (Eq. 9). $VaC_j = VaC_j^0 * Rev_j$

The fixed vessel costs FxC_j, are administration costs, insurance, maintenance, etc. The capital costs CaC_j include both depreciation and interest costs. Both fixed vessel costs and capital costs are assumed dependent on the value of the vessel (Eq. 10). The costs per fleet are calculated as an average amount per vessel multiplied by the number of vessels in the fleet *j* ($\mathrm{Fle_j}$) times an indexed price per vessel to account for changes in construction costs per fleet over time ($\mathrm{price_j^{inv}}$).

$$FxC_j = FxC_j^0 * Fle_j * price_j^{inv}$$

$$CaC_j = CaC_j^0 * Fle_j * price_j^{inv}$$

The core equation of the fleet dynamics module is the Cobb-Douglas catch equation (Cobb and Douglas, 1928). It describes a non-linear relationship between catch, biomass and effort (Eq.5). Catch of age class *c* of species *i* by fleet *j* fisheries *k* in area *n* depends on the fishing effort and the available biomass ($\mathrm{B_{i,c,n}}$). Fishing effort is only part of the total effort in days at sea $\mathrm{Eff_{j,k,n}}$ which includes steaming time. The proportion of time steaming to reach area *n(* $\gamma_{\mathrm{j,n}}$) are provided by the user and should vary according to the distance between the home port of the fleet and the fishing area n and possibly take into account that larger vessels can go further offshore. $\mathrm{C_{i,j,n}^0}$ is a measure of the catchability of the biomass in area *n* and $\mathrm{t_j}$ is a measure of technological progress *α and β are the* output elasticities of effort and biomass, respectively.

$$Catch_{i,c,j,k,n} = C_{i,c,j,n}^{0} * \left(1 + t_j\right) * \left(\frac{Eff_{j,k,n}}{1 - \gamma_{\mathrm{j,n}}}\right)^{\alpha_j} * B_{i,c,n}{}^{\beta_j}$$

<u>Constraints on catch/landings</u>

If the species is managed through quotas, landings for each fleet are constrained by the quota of the species. The quota allocated to each fleet is a fixed proportion $csh_{i,j}$ of the species

TAC. The proportion $csh_{i,j}$ is calculated from historical data and assumed to remain fixed to mimic the European relative stability *(EEC, 1992).*

$$Land_{i,j,c} = Catch_{i,j,c} - Disc_{i,j,c}$$

$$Disc_{i,j} = \begin{cases} Catch_{i,j} - TAC_i \cdot csh_{i,j} & if\ Catch_{i,j} > TAC_i \cdot csh_{i,j}\ \&no\ \ LO \\ 0 & otherwise \end{cases}$$

Catch of fish below legal size is assumed proportional to the legal-size catch of the target species *h* with a discard rate $dsh_{i,c,h,j,n}$.

$$Udisc_{i,c,j,n} = \sum_h Catch_{h,j,n} * dsh_{i,c,h,j,n}$$

In the status quo situation, over-quota catch and undersize fish can be discarded. In case of landings obligation (LO), implementation is assumed perfect and over-quota discards are set to 0 and undersize catch is removed from the quota.

The catch is also limited by the available. Within a year for each age class *c*, species *i*, and area *n* the catch and undersized discards cannot exceed the available biomass $B_{i,c,n}$.

$$\sum_j \left(Catch_{j,i,c,n} + Udisc_{j,i,c,n}\right) \leq B_{i,c,n}$$

Constraints on effort

The catch are limited by the quota available to the fleet but also by the amount of effort that a fleet can deploy. The number of vessels in a fleet constrains the available days at sea with a lower and a higher bound. The maximum effort can be defined in two ways, as the maximum number of days at sea by a vessel ($dasM_j$, based on observations) multiplied by the number of vessels or as a management limit for the whole fleet ($maxEff_j$). The lower of the two is used as upper limit and a predefined percentage $\mathrm{Eff}^{\min}$ of the upper limit is used as lower bound.

$$Eff^{min} \cdot \min(maxEff_j, \quad dasM_j \cdot Fle_j) \leq \sum_{k,n} \left(Eff_{j,k,n}\right) \leq \min(maxEff_j, \quad dasM_j \cdot Fle_j)$$

Biology

The stock biomasses are updated at the end of the year based on the total catch of the year and on the stock productivity. The stock dynamics can be modelled in three different ways depending on the option chosen for each species. Productivity $P_{i,y}$ can be calculated with surplus production models of the polynomial or logistic).

$$P_{i,y} = \delta_{0,i} + \delta_{1,i} \cdot B_{i,y} - \delta_{2,i} \cdot {B_{i,y}}^2 + \delta_{3,i} \cdot {B_{i,y}}^3$$

Where the $\delta_{k,i}$ polynomial coefficients are provided by the user.

$$P_{i,y} = r_i \cdot B_{i,y} \cdot \frac{1 - B_{i,y}}{K_i}$$

Where r_i is the intrinsic growth rate of the species and K_i the carrying capacity.

The biomass at the end of the year is then simply the initial biomass plus productivity minus total catch. The total catch accounts for the catch by fleets not in the model assuming they represent a proportion $\left(1 - \sum_j csh_{i,j}\right)$ complementary to the catch shares $csh_{i,j}$ of the fleets in the model.

$$B_{i,y} = B_{i,y-1} + P_{i,y-1} - \left(\sum_j \left(Catch_{j,i,c} + Udisc_{j,i,c}\right)\right) / \sum_j csh_{i,j}$$

Alternatively an age-structured model can be used (similar to the one described in Simons et al., 2014). The biomass at age $B_{i,c,y}$ is the product of the number of fish $N_{i,c,y}$ and the average weight of individual fish per age class $w_{i,c}$.

$B_{i,c,y} = N_{i,c,y} \cdot w_{i,c}$

The number of individuals is computed using the survival equation with the Pope approximation (Pope, 1972). Surviving individuals from class *c* grow to class *c+1* in the following year with two sources of mortality, natural mortality $M_{i,c}$ and catch at age catch (Eq. 22).

$$N_{i,c+1,y+1} = N_{i,c,y} \cdot e^{-M_{i,c}} - \left(\frac{\left(\sum_j \left(Catch_{j,i,c} + Udisc_{j,i,c}\right)\right)}{w_{i,c} \cdot \sum_j csh_{i,j}}\right) \cdot e^{-M_{i,c}/2}$$

The last class is considered a plus group and calculated as sum of survivor of the plus group and the survivor of the class below. The recruitment is calculated using segmented regression stock recruitment relationship with input coefficients a_i and b_i (Eq. 23). The spawning stock biomass $SSB_{i,y}$ is the sum of product of the biomass at age and the maturity index at age $mat_{i,c}$ (Eq. 24).

$$N_{i,1,y+1} = \begin{cases} a_i \cdot SSB_{i,y-1} & if\ SSB_{i,y-1} < b_i \\ a_i \cdot b_i & if\ SSB_{i,y-1} \geq b_i \end{cases}$$

$$SSB_{i,y} = \sum_c \left[B_{i,c,y} \cdot mat_{i,c}\right]$$

The spatial distribution of the stock is exogenous, at the beginning of every year the new biomass is redistributed to the areas according to a predefined distribution factor $dist_{i,c,n,y}$. The factor can be age specific if the stock is. Within a year the biomass in an area can be completely depleted but it will be redistributed at the beginning of the following year. To account for long term displacement of species, the spatial distribution can vary in time if different distributions are provided.

$$B_{i,c,n,y} = dist_{i,c,n,y} \cdot B_{i,c,y}$$

Prices

Fish and fuel prices are calculated in the model. To capture inflation, prices are changed using an annual trend factor expressed as the percentage of change per year (r^{fuel} and r^{fish}). Fish prices can also change because of price elasticity ε_i, with prices increasing/decreasing when the volume landed decreases/increases in year y compared to the previous year. Including price elasticity is only relevant if the fleets land a significant share of the total supply of a species. Setting price elasticity at zero leads to prices only changing due to inflation.

$$price_{j,y}^{fuel} = price_{j,y-1}^{fuel} \cdot r^{fuel}$$

$$price_{i,j,c,y}^{fish} = price_{i,j,c,y-1}^{fish} \cdot \left(\frac{\sum_j Land_{i,j,y}}{\sum_j Land_{i,j,y-1}}\right)^{-\varepsilon_i} \cdot r^{fish}$$

Prices are set as real prices between 2010 and 2014. Because dramatic fuel price changes happened in recent years, from 2015, fuel price is set as the average of the 2010-2014 value. Fish prices remained at 2014 values.

Long-term behaviour – Investment

In the model, entry and exit in fleets are considered the only investment. The size of a fleet is determined by the size of the fleet in the previous year plus the (dis)investments. It is assumed that there are no access costs related to entry and exit in the fleet. $Fle_j^y = Fle_j^{y-1} + Inv_j^{y-1}$

Theoretically the investment should be determined by expectations of future profit, in the model we use the profitability for the fleet in the previous year as indicator of the state of the fishery to estimate the willingness to (dis)invest in the fleet (Figure 2).

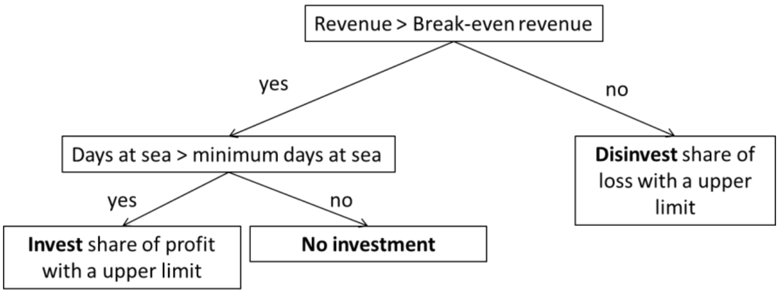


Figure 2 Decision rule on investment and disinvestment

The profitability is defined by comparing the break-even revenues to realised revenues. The break-even revenue (BeR_j) is determined as the revenue needed to cover both fixed[1] and variable costs (Eq. 14). In case the revenue is higher than the break-even revenue and the fleet uses enough of its potential total effort investment will happen whereas if the revenue is lower than break-even revenue the fleet will disinvest.

$$BeR_j = Rev_j \frac{CrC_j - FxC_j - CaC_j}{Rev_j - (FuC_j + VaC_j)}$$

The level of (dis)investments Inv_j per year is determined using the profit margin (net profit divided by revenue) available for investment. Disinvestment happens when the revenue is lower than break-even revenue. To obtain the total investment for a fleet the profit margin is

[1] Crew costs are here considered a fixed cost for several reasons: 1) skipper ownership is commonplace making it difficult to separate remuneration of labour and capital; 2) crews wages calculated as shares could be unacceptably low at break-even level making the work as crew unattractive and it is doubtful that operating at break-even level could be continued indefinitely, while that is precisely the principle of break-even.

multiplied by the number of vessels. It can be assumed that only a share psh_j of the profit margin can be invested, by default it is set to 100%. This calculation may lead to extreme changes in the number of vessels in a fleet, which could occur as vessels from other fleets may enter the given fishery. However, the inertia of the system (licensing, knowledge of skippers, etc.) probably does not allow such full flexibility. Consequently, the change in fleet size are capped to a proportion of the fleet (Inv_j^{max} for investment and Inv_j^{min} for disinvestment).

$$Inv_j = \begin{cases} \min\left(Inv_j^{max} \cdot Fle_j,\quad psh_j \cdot \dfrac{Rev_j - BeR_j}{Rev_j} \cdot Fle_j\right) & if\ Rev_j \geq BeR_j\ \&\ \sum_n \left[Eff_{j,n}\right] \geq Cap_j^{min} \\ \max\left(-Inv_j^{min} \cdot Fle_j,\quad psh_j \cdot \dfrac{Rev_j - BeR_j}{Rev_j} \cdot Fle_j\right) & if\ Rev_j < BeR_j \\ 0 & in\ all\ other\ cases \end{cases}$$

Where Cap_j^{min} is the minimum effort that should be used in the fleet before considering new entries.

Policy

Several management measures can be included in the model: effort limitation (see effort constraint in fleet dynamics), spatial closures, TACs and landing obligation.

Spatial closures are implemented by closing a part of areas (defined by the user for each area). The biomass within an area is assumed to be homogenously distributed so the closure would limit the access to the available biomass in the area proportionally to the closure transforming constraints on catch per area into :

$$\sum_j \left(\frac{Catch_{j,i,c,n,y} + Udisc_{j,i,c,n,y}}{1 - clos_{j,n,y}}\right) \leq B_{i,c,n,y}$$

In TAC-managed fisheries the landings of the fleets are constrained by their available quota. In multispecies fisheries, additional options can be chosen to allow over-quota catches or not. The TAC is calculated using the Baranov equation and a target fishing mortality (Lassen, 2000) with a pre-defined limit on the possible inter-annual variation. In addition the discards can be removed from the TAC using the observed discard rate $discR$ by setting $discOut$ to 1.

$$TAC_{i,y} = discOut \cdot (1 - discR) \cdot \sum_c B_{i,c,y-1} \cdot \frac{F_{i,c,y}^{tac}}{F_{i,c,y}^{tac} + M_{i,c}} \cdot \left(1 - e^{-(F_{i,c,y}^{tac} + M_{i,c})}\right)$$

The fishing mortality ($F_{i,,y}^{tac}$) used to calculate the TAC can be defined in several ways.

Option 1 – Flatfish management plan (2010 – 2015)

- If the SSB is outside safe biological limits (defined as $Blim_i$), the fishing mortality is reduced by the maximum allowed percentage change per year fsh_i. If the previous fishing mortality was higher than the management target F_i^{tar} it is reduced up to the maximum allowed change
- Otherwise the management target is used.
- If the resulting TAC deviates by more than 15% from the previous year TAC, the TAC is then set at previous TAC +/- 15%

$$F_{i,y}^{tac} = \begin{cases} \overline{F_{i,y-1}} \cdot (1 - fsh_i) & if\ \overline{F_{i,y-1}} \cdot (1 - fsh_i) \geq F_i^{tar}\ or\ SSB_{i,y-1} \leq Bpa_i \\ F_i^{tar} & otherwise \end{cases}$$

Option 2 – Fixed F (from 2016) at Fmsy for the Baseline, or transitioning to Fmsy (2016-2020) for the CFP 2020

- the management target F_i^{tar}, is used to calculate the TAC

Option 3 – Multi-annual plan (from 2016) at lower and higher bound of Fmsy range

- Bpa_i is used as a safeguard, if the SSB falls below the safeguard, the fishing mortality is reduced to reach the safeguard within 5 years.
- Otherwise the management target is used.

To take into account the catch composition of age-structured stock, partial fishing mortalities at age $F_{i,c,y}^{tac}$ are calculated using $\overline{F_{i,y}}$ the average for age classes considered to be fully exploited.

$$F_{i,c,y}^{tac} = F_{i,y}^{tac} \cdot F_{i,c,y-1} / \overline{F_{i,y-1}}$$

For the non-age structured stocks, instantaneous fishing mortality F_i is calculated indirectly from harvest rate H_i.

$$\overline{F_{i,y}} = -\log(1 - H_{i,y})$$

$$H_{i,y} = \frac{\sum_j Catch_{i,j,y} / \sum_j csh_{i,j}}{B_{i,y}}$$

For the age structured stock, the fishing mortality at age is calculated from the survival equation.

$$F_{i,c,y} = -log\left(\frac{N_{i,c+1,y+1}}{N_{i,c,y}}\right) - M_{i,c}$$

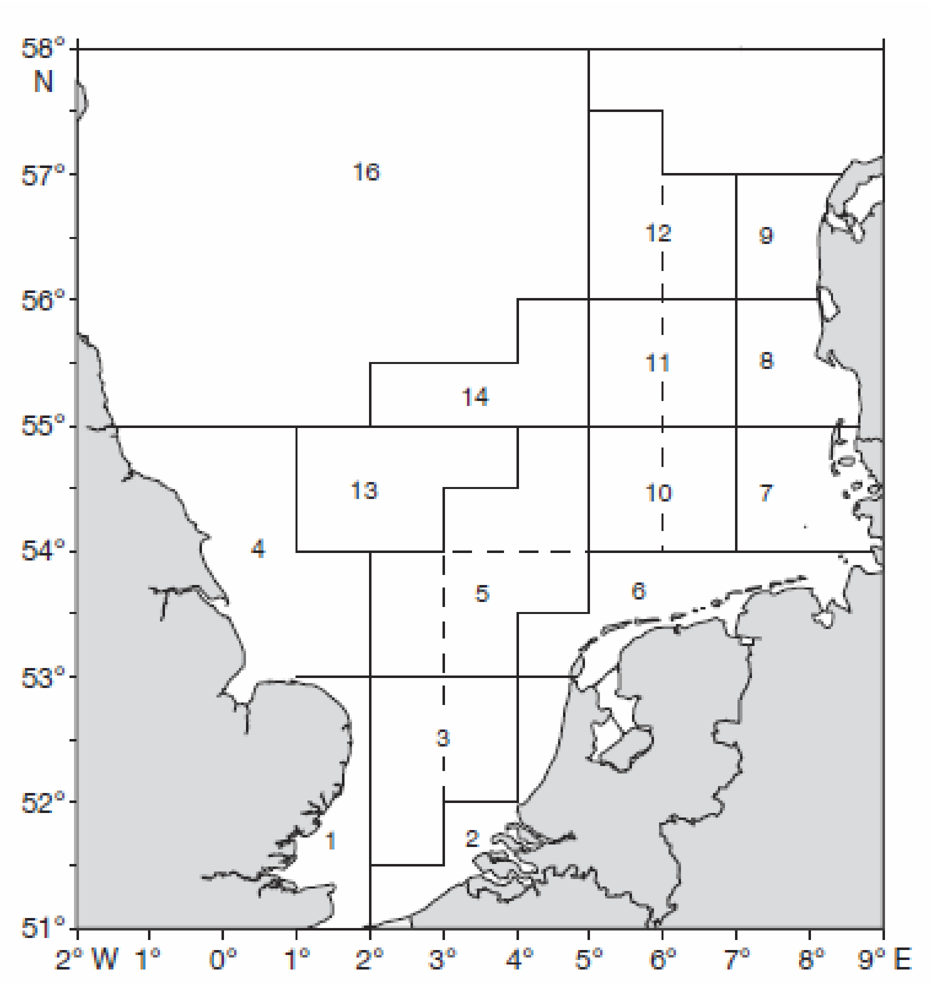
The landings obligation is implemented as planned in the 1st phase (2016-2019) on the species which define the fisheries (Article 15.1c, Regulation (EU) 1380/2013). In the case of the North Sea flatfish fishery, discards of sole and plaice will then be forbidden and those will have to be brought back to the harbour. Since Plaice is the most discarded species of the fleet, this means that 40% of all discarded bycatch are captured in phase 1. Most of the assumptions used in this study were taken from Buisman et al 2013:

additional crew costs due to sorting and handling	EUR 0.21/kg discards +1.5 FTE/vessel
additional steaming cost due to limiting capacity for midsize vessels (18-24m)	30% of current steaming costs
additional variable costs (ice, landings, transport)	EUR 0.15/kg discards
Price of landed discards	EUR 0.15/kg

III.2 Case study and input data description

The case study is the flatfish and shrimp fisheries in the North Sea, including:

- 3 species: sole (Solea solea), plaice (Pleuronectes platessa) and shrimp (Crangon crangon)
- 6 fishing fleets: German beam trawlers 12-18m (DE_TBB_1218), German beam trawlers 18-24m (DE_TBB_1824), Dutch beam trawlers 12-24m (NL_TBB_1224), Dutch beam trawlers 24-40m (NL_TBB_2440), Dutch beam trawlers >40m (NL_TBB_40XX) and British beam trawlers >24m (GB_TBB_24XX)
- spatial resolutions: 16 areas of the North Sea detailed in Figure 3.



a)

Figure 3 North Sea divided in 16 areas (source Rijnsdorp et al 2012)

The model is calibrated with both economic data and biological data.

The initial biomass of the three species was taken as an average of the 2008-2010 biomass. For sole and plaice the biomass was taken as the total biomass from ICES (ICES, 2012b), for shrimp it was taken as the commercial size stock from ICES (ICES, 2012a).

The initial spatial distribution of the stocks is shown on Figure 4 as the density of fish per area. The shrimp distribution was calculated using standardized German and Dutch commercial CPUE while the distribution of sole and plaice was based on area specific growth rate for different size classes that were translated into age classes (Teal et al., 2012), note that only the total average distribution is shown in Figure 4. Sole and plaice stocks are structured by age using ICES data with segreg stock recruitment relationships while the productivity of the shrimp stock is held constant at the average productivity of 2000-2010 calculated using the annual biomass estimates and international catches (Table 4 in appendix).

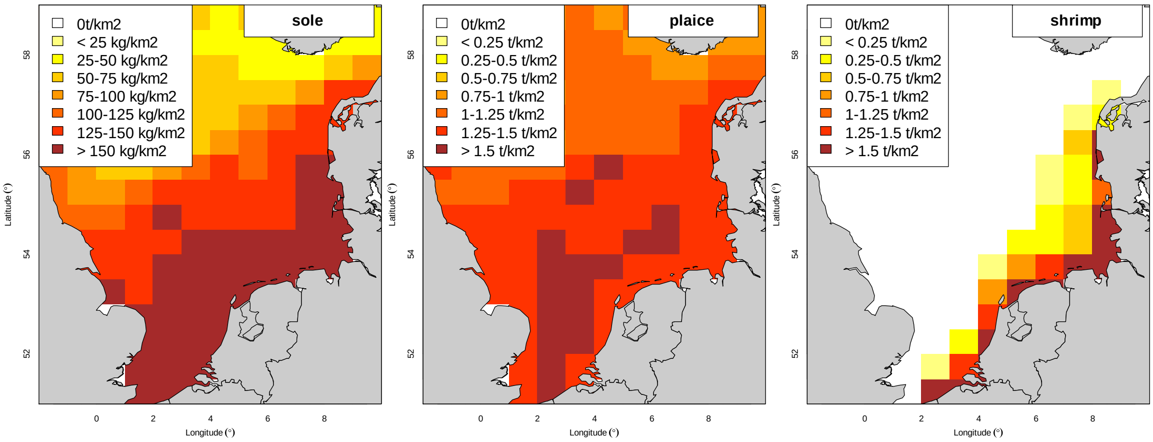


Figure 4 Initial annual species distribution for sole, plaice and shrimps (different scales)

Table 1 Stock productivity parameters

Species	Model type	Parameters	Initial biomass	Reference points
Sole	Age structured with segreg stock recruitment relationship	M, Mat, N, w (from WGNSSK 2012); $a_i = 3.4532$; $b_i = 27\,348.0185$	49 594t	*Bpa =* 35 000t
Plaice	Age structured with segreg stock recruitment relationship	M, Mat, N, w (from WGNSSK 2012); $a_i = 7.2122$; $b_i = 131\,528.987$	568 021t	*Bpa =* 230 000t
shrimp	Polynomial :	$\delta_{0,i}$ =46751t ; $\delta_{1,i}$=0; $\delta_{2,i}$=0; $\delta_{3,i}$=0	99 999t	None

The fleets were selected as they target either flatfish (sole and plaice) or shrimps and they are important fleets for the fisheries. For the six fleets included in the model, catch and effort data were provided by national fisheries research institutes in the project VECTORS: LEI for the Dutch fleets, TI for the German fleets and CEFAS for the British fleet. The economic data was taken from Anderson et al (2012). The fleets were parameterised based on data for 2008-2010. Three fleets (DE_TBB_1218, DE_TBB_1824 and NL_TBB_1224) are mainly dependent on shrimps with more than 75% of their fishing revenue from shrimp while the flatfish fleets (GB_TBB_24XX, NL_TBB_2440 and NL_TBB_40XX) land a broader combination of species, sole and plaice representing about 80% of their revenue (Figure 5). For all the fleets, the three species cover between 75% and 100% of the revenue and the six fleets cover 51% of plaice quota, 69% of sole quota and 84% of the shrimp landings (Figure 6).

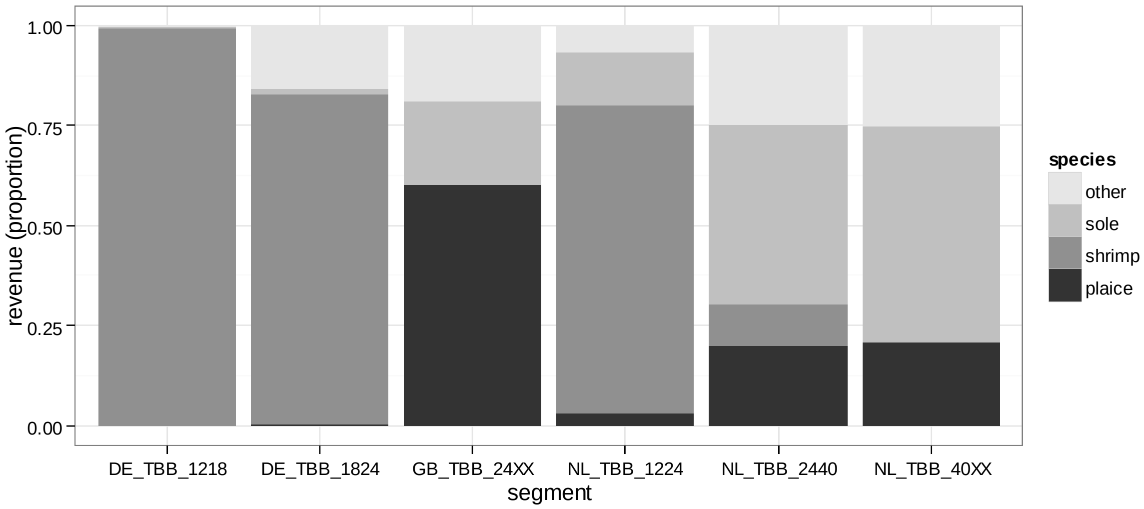


Figure 5 Composition of revenue in term of species for the 6 selected fleets

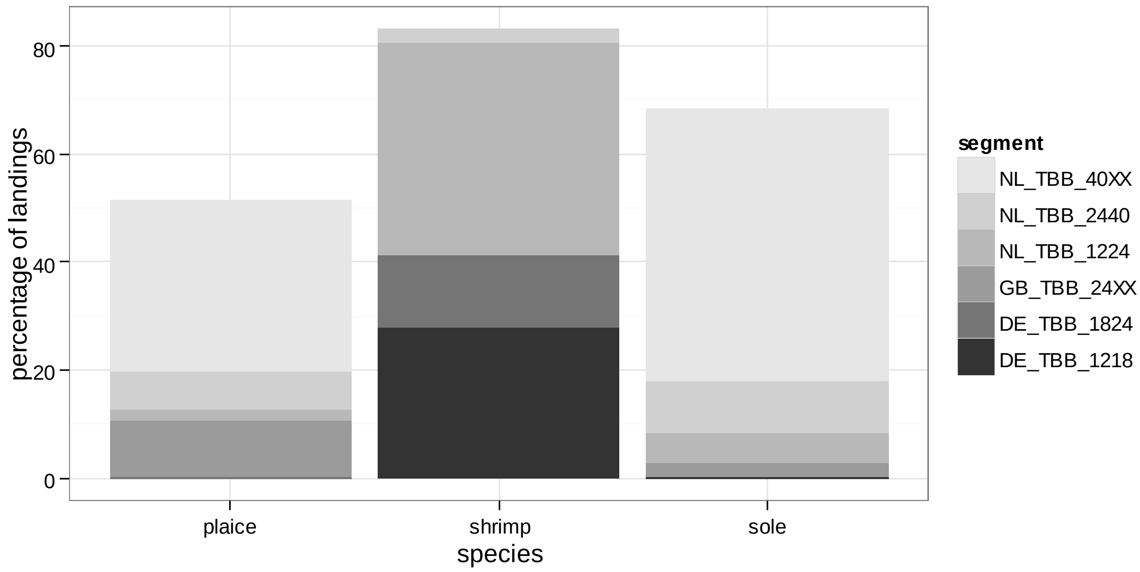


Figure 6 Percentage of landings covered by the fleets in the model

III.3 Indicators

Simfish can compute the standards biological and economic indicators:

Indicators at the stock level:

- SSB (for stock with age structure)/ total Biomass
- Fbar
- Landings/Discards
- TAC

Indicators at the fleet level

- Gross value Added (GVA)
- Profit

- Profitability
- Effort
- Fleet size (vessel numbers)
- Catch
- Revenue

III.4 Results

Baseline results

Setting the TACs at the level defined with Fmsy for sole and plaice (baseline scenario) leads to high biomass levels for sole and plaice

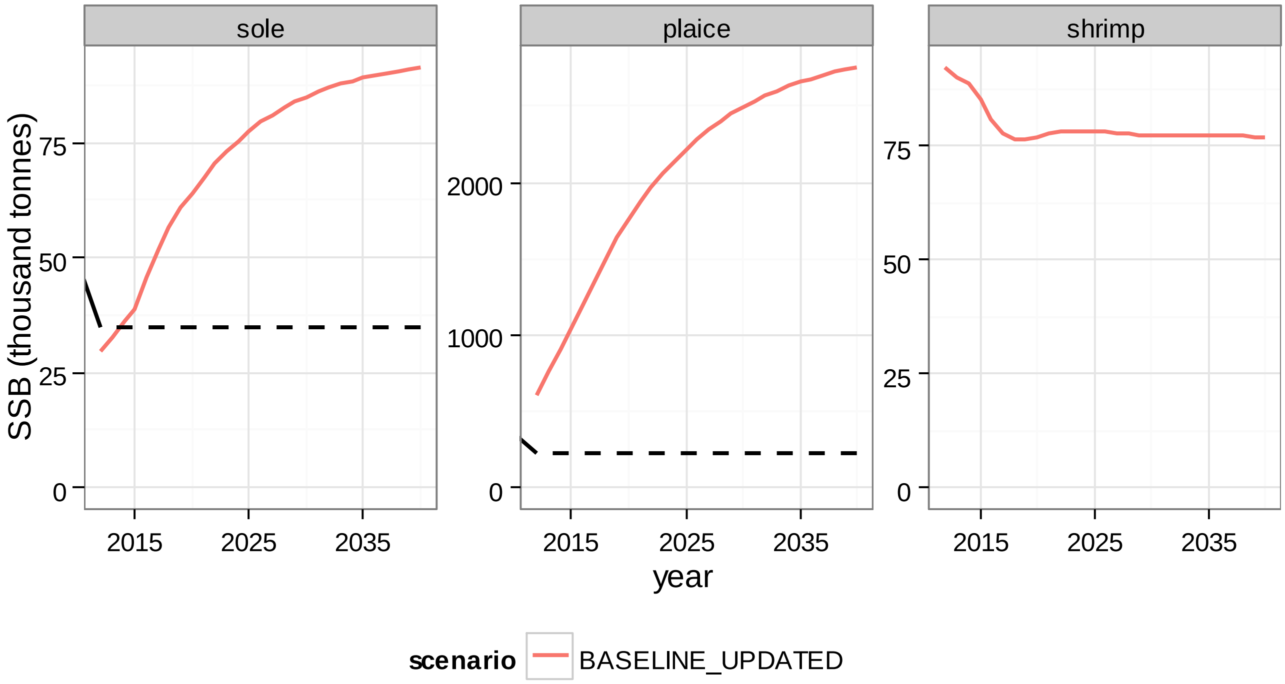


Figure 7 SSB of sole, plaice and shrimp in the baseline scenario

The initial decrease in TAC leads to a drop in profitability quickly compensated by higher stocks and higher TAC and catch rates.

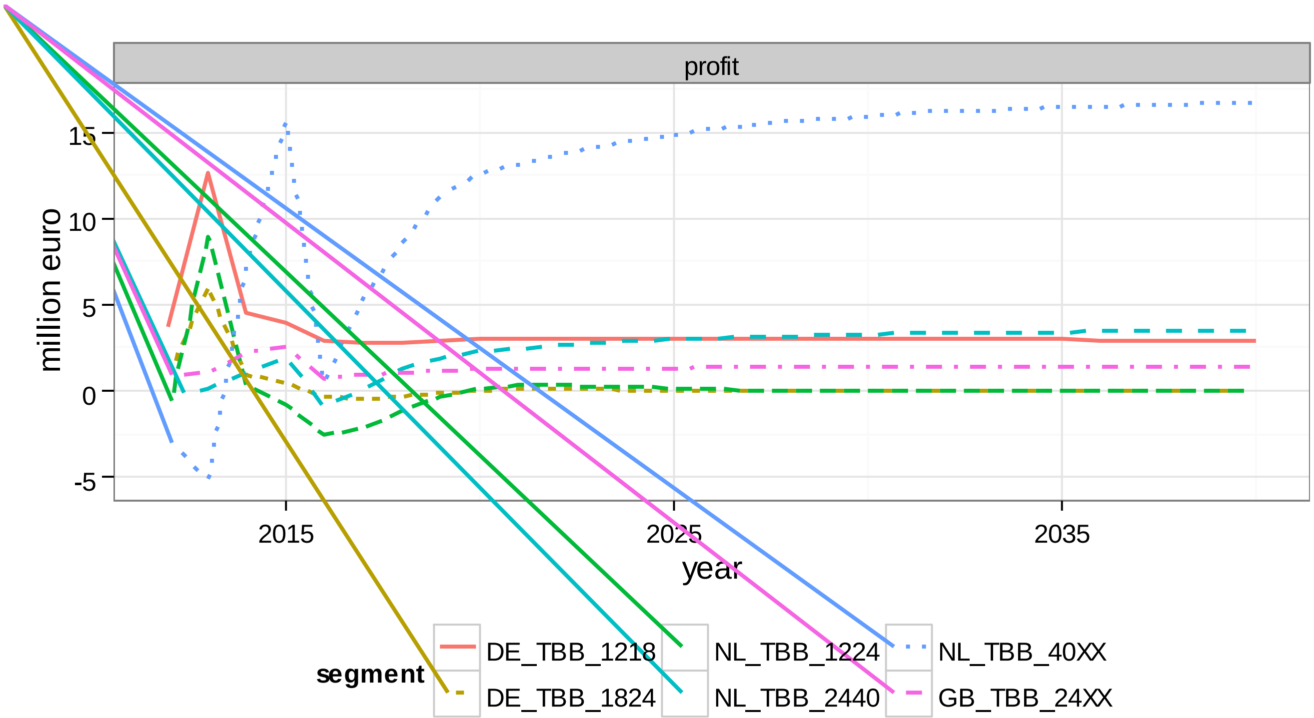


Figure 8 profit of flatfish and shrimp fleets in the baseline scenario

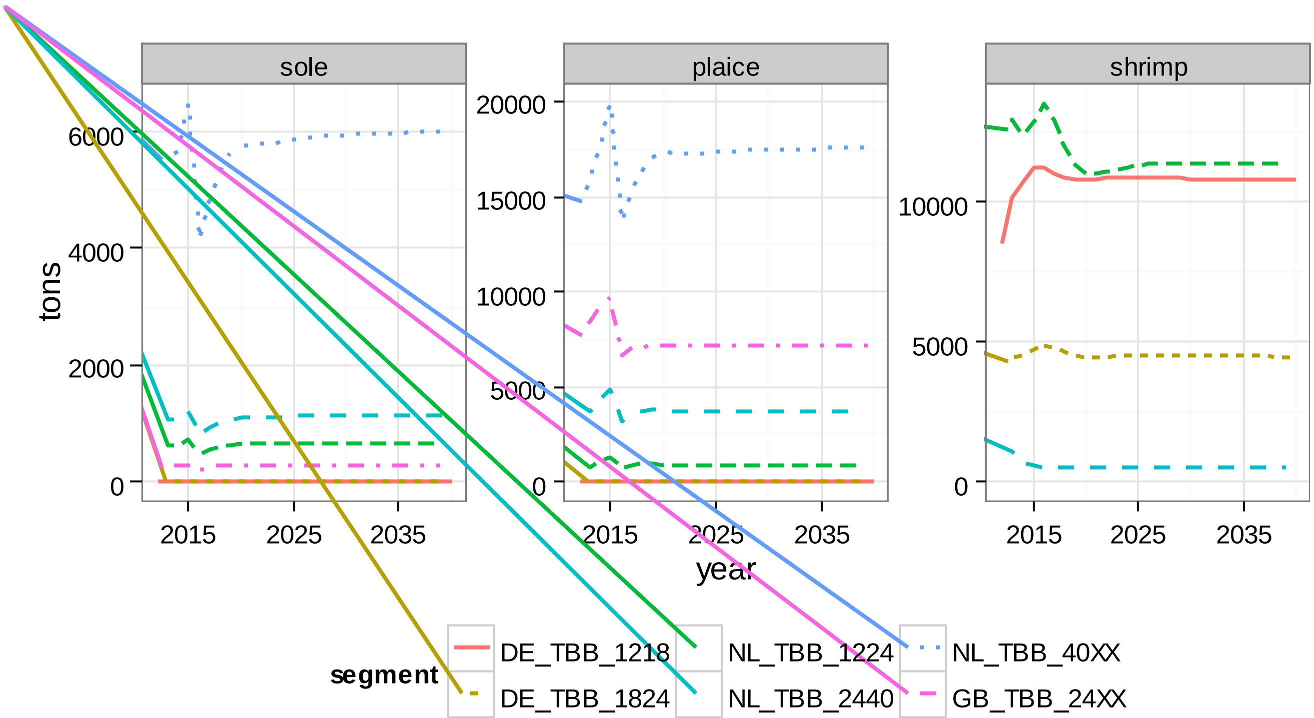


Figure 9 Landings of the three main species by the fleet segments in the model

Scenarios

Biological and economic indicators were computed from the SIMFISH results. The resulting biomasses don't differ much for the different scenarios, while the fishing mortalities differ greatly, the higher the F, the higher the catch and the lower the biomass.

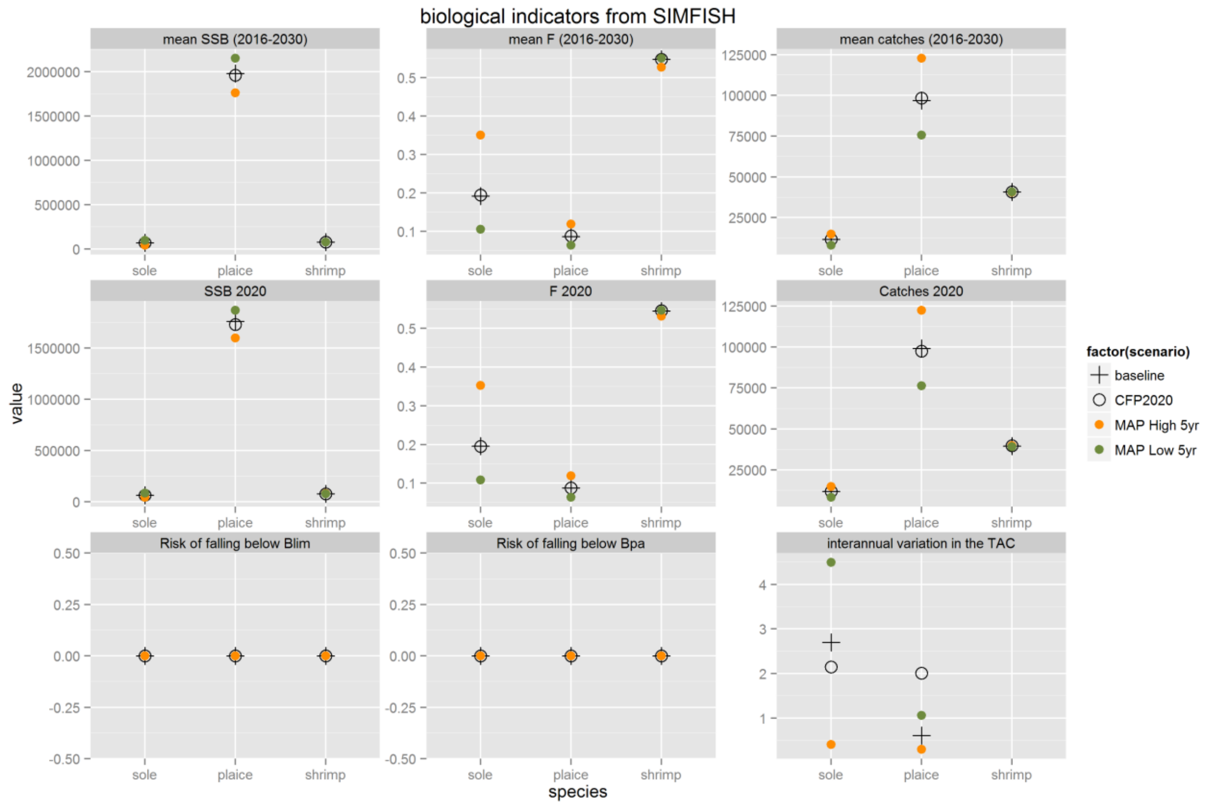


Figure 10 Biological indicators for the 4 scenarios

Economic indicators show that the most affected fleet are the fleets that are highly dependent on flatfish. (NL2, NL3 and UK1). Although low F will lead to losses in the first few years (higher negative profit) the long term profit (net present value, NPV) is higher.

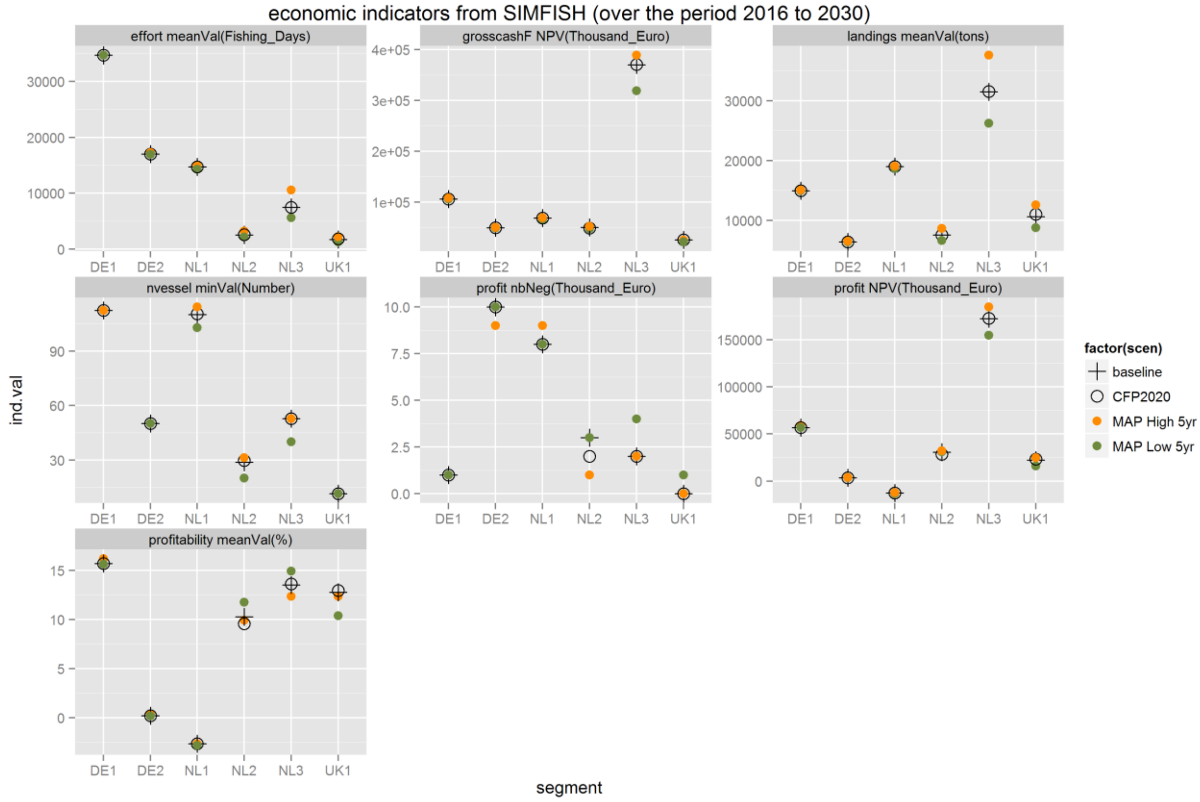


Figure 11 Economic indicators for the 4 scenarios

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ANNEX IV – FISHRENT DESCRIPTION

1 Model Settings

The model accounts for ten fleet segments covering vessels from Denmark, England, France and Germany. According to the Data Collection Framework (DCF) fleet segments were classified by vessel length and predominant gear type (European Commission, 2010). The model was run on an annual time step for a period of 10 years (2013-2023). It accounted for four stocks (see Figure 1).

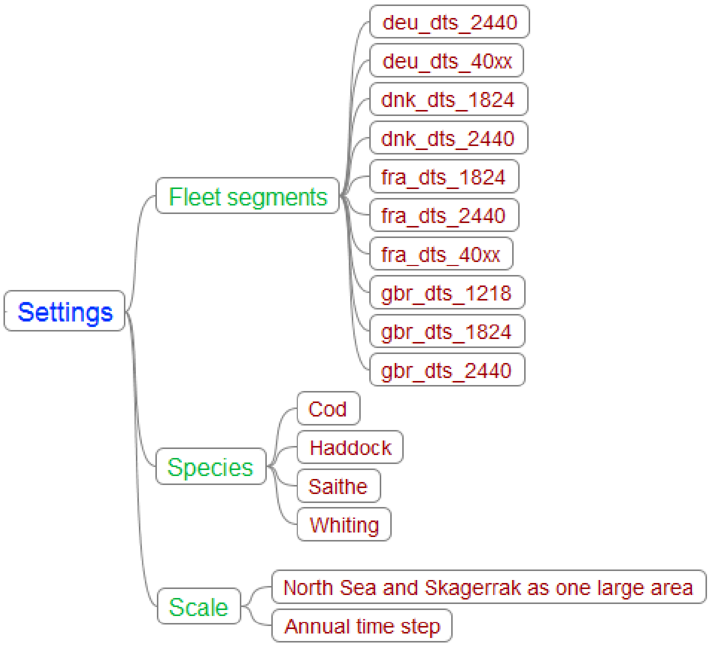

Fig.1: Settings of the model

Low recruitment values of the period 1988 to 2013 were used for cod, haddock and saithe to parameterize the stock recruitment function. For whiting the complete timeseries was used. For all modelled species recruitment was predicted based on stochastic simulations applying a Hockey stick stock-recruitment relationship. The calibration of the model was based on average biological (ICES working group reports) and economic data (Annual Economic Report) for the period 2009-2012 (e.g. see Anderson and Guillen, 2009; ICES, 2013) (see Figure 2).

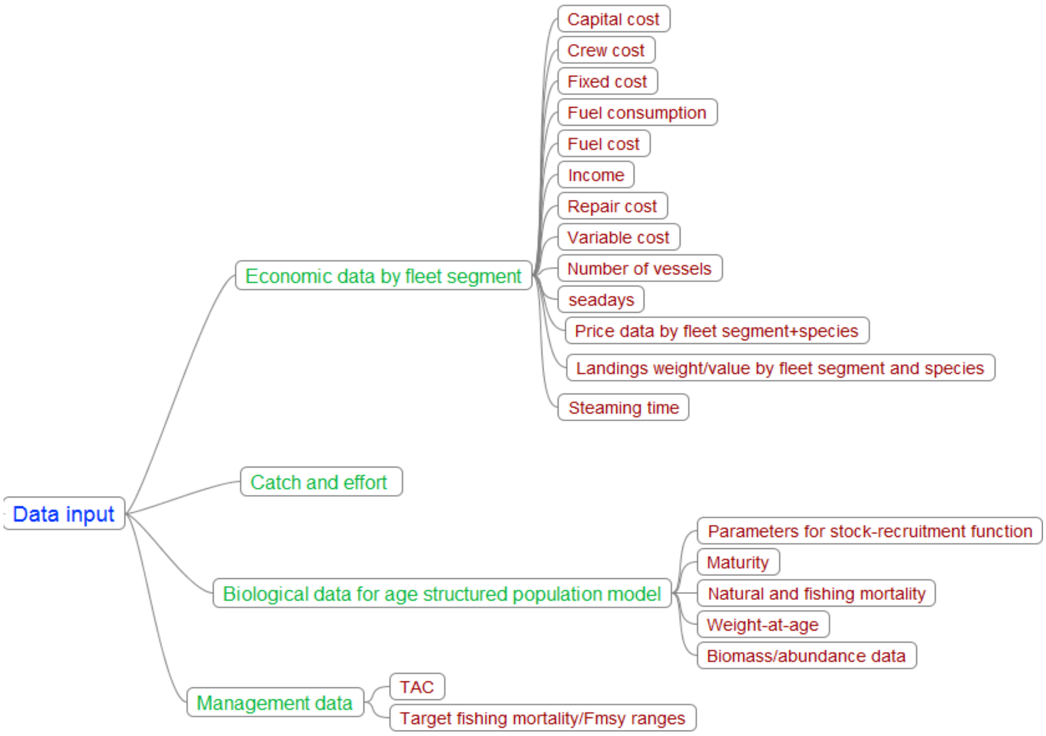

Fig.2: Data input for FishRent

2 MODEL DESCRIPTION

The modelling approach is based on a bio-economic optimisation and simulation model called "FishRent" (Salz et al., 2011; Simons et al., 2014). It is a dynamic feedback model and is composed of six sub-modules (Figure 3). The model does account for the fact that economic conditions (e.g. revenues and fishing costs) will determine fishing effort and that changes in regulations can alter relative profitability and hence subsequent effort decisions by fleet segments, which in turn will impact the commercial fish stock.

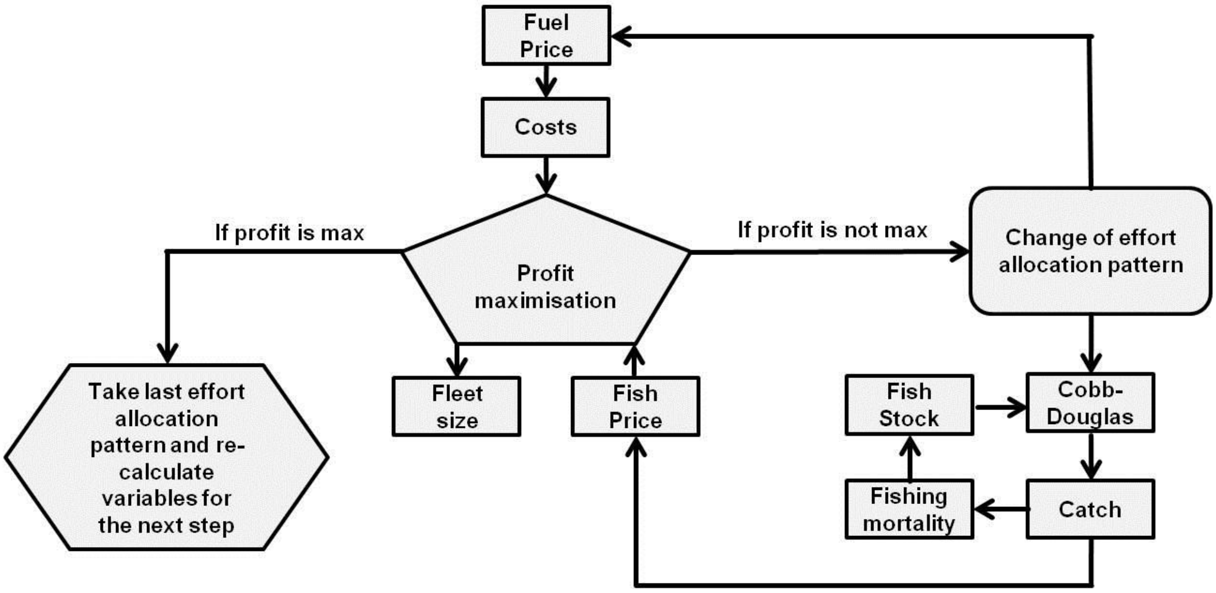

Fig 3: Conceptual design of FishRent

It is a model of a fishery system which focuses on the economic drivers, among which the profit earned by the fleet segments is the main driver. Profit depends on the amount of landed fish, prices for the landed fish, and the costs of fishing including fuel costs, variable costs, crew costs, capital costs (e.g. depreciation and interest payments) and fixed costs (e.g. administrative costs, insurance and maintenance costs). Profit, furthermore, depends on the interest rate for capital invested in the fleet. Profit generated from other non-explicitly modelled species or areas are taken into account in the model as a fixed proportion of the revenue. In the model profits from two years ago, determine the level of investment or disinvestment in the fleet (for details see (Salz et al., 2011)). Any fleet segment that is highly profitable will become bigger and hence the profit of the individual vessels would dissipate in the long-term, given that free access in the fisheries is allowed. It is presumed that fleet segments seek to maximise profits by setting an optimal level and spatio-temporal distribution of fishing effort, which in turn impacts the fish stock. Thereby it is assumed that fishermen have a perfect knowledge about potential catch rates.

In the model, each year, the applied CONOPT solver (for the detailed description of the CONOPT algorithm see (Drud, 1991)) uses various levels of fishing effort for each fleet segment within minimum and maximum levels of each fleet segment in the Cobb-Douglas production function and with regard to the cost, revenue and overall profit function. The effort level that results in the maximum overall annual profit of all modelled fleet segments is then used for further calculations. This optimal effort level used in the Cobb-Douglas production function (for details see (Salz et al., 2011)) provides a catch estimate, which is then used in the Pope's approximation (Pope, 1972) to calculate the number of individuals of *i*th age at time *t*:

$$(1) \qquad N_{t,i,k} = N_{t-1,i-1,k}e^{-M_i} - \sum_j \left(\frac{C_{t-1,i-1,k,j}}{s_{i,k,j}}\right) e^{-\frac{M_i}{2}}$$

Where $N_{t,i,k}$ is the number of fish of ith age in kth area at time t, $C_{t,i,k,j}$ is the catch in numbers of ith age, in kth area and jth fleet segment at time $t-1$ and $s_{i,j,k}$ is the catch share for ith age, in kth area and jth fleet segment (constant over time). The catch share serves to estimate the total catch of a species considering the catches of non-modelled fleet segments. M_i is the instantaneous natural mortality rate for ith age. In turn, the estimated number of individuals is then used in equation 3 to calculate the age-specific instantaneous fishing mortality

$$(2) \qquad F_{t,i,k} = -\ln\left(\frac{N_{t,i,k}}{N_{t-1,i,k}}\right) - \quad M_i$$

A Cobb-Douglas production function was chosen to calculate the catch as it assumes that fishing mortality is not directly proportional to effort and yield not proportional to stock size.

Moreover, individual fish grow according to the von Bertalanffy weight-at-age function (von Bertalanffy, 1938). For the case study the parameters used in this function were estimated directly from weight-at-age data of the modelled stock (ICES, 2013). Once a year, stochastic recruitment (the number of fish of age three at the beginning of the year) is calculated via a Hockey stick stock-recruitment function. Each time the stochastic recruitment model is employed, 100 stochastic iterations are run. At the end of each year, all fish of ith age are moved to the next age class. All fish older than the maximum age are accumulated in the last age class (plus group at age 10s).

A Baranov function (Baranov, 1918) that includes the target fishing mortality rate of the management plan is used to determine the TAC for the next year.

$$(3) \sum_i \left[TSB_{t,i} \times \frac{\left(\frac{F_{t,i}}{Fbar_t}\right) \times Ftar_t}{\left(\left(\frac{Ftar_t}{Fbar_t} \times F_{t,i}\right) + m_{i,t}\right)} \times \left(1 - e^{-\left(\left(\frac{Ftar_t}{Fbar_t} \times F_{t,i}\right) + m_{i,t}\right)}\right) \right]$$

Where $TSB_{t,i}$ is the total stock biomass of ith age at time t calculated as the product of number of individuals and mean weight-at-age. $Ftar_t$ is the target fishing mortality, $Fbar_t$ is the average fishing mortality for certain age classes as used by ICES, $F_{t,i}$ is the instantaneous fishing mortality and $m_{i,t}$ is the instantaneous natural mortality. Technically fish prices per age are included in the model but no further investigation was performed. Fuel prices are fixed over time.

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Adding economics to FCube
Notes

immediate

April 8, 2015

Contents

1 Introduction

This analysis is recovered from WKBEM. The idea was to compute costs per unit of effort at the metier level of the fleet as defined in DCF level 4 (aka "gear" for shortness). Mainly that's the aggregation we use for stock assessment and forecasting. So that it's possible to scale information, e.g. aggregated for MAPs analysis, and add an economic component to it.

The costs were computed at the metier level as a weighted average of the costs reported by member states at the level of the so called fleet segment. Using these data a set of mixed effects models were fit using the fleet segment as a random effect and as fixed effects member state, year (only for variable costs), gear (metier level 4) and length-over-all. Finally a set of predictions were carried out to compute the modeled value and confidence intervals (0.95).

Note that:

- variable costs = energy costs + other variable costs + repair and maintenance costs
- fixed costs = annual depreciation costs + other non variable costs + license costs
- crew costs = crew wage + unpaid labour

1.1 Data quality

In a recent meeting (Zagreb's workshop) the quality of the data was discussed and their conclusions was that each member state was processing the effort data differently. This situation has an impact on the analysis. IMO there are two issues that must be taken into account when using this dataset:

- Predictions shouldn't be crossed between member states. If one needs to fill gaps in data should do it as muh as possible using the same member state data.
- The analysis of costs time series should be made relative. Using ICES jargon, should be used only for trends.

We'll try to stick to these recommendations although is not always possible.

```
# ====================================================
# libraries and constants
# ====================================================
# rm(list=ls())
library(lattice)
library(MASS)
library(plyr)
library(dplyr)
library(reshape2)
library(lme4)
library(ggtern)
source("funs.R")

# period
yrs <- 2008:2012

# ==================================================== Read
# data ====================================================

# codes
codes.ft <- read.csv("fishingTech.csv")
codes.gr <- read.csv("gearTypes.csv")
codes.loa <- read.csv("loa.csv")
```

```
codes.ms <- read.csv("ms.csv")

# data
eff.orig <- read.csv("effort_by_gear.csv", sep = ";", stringsAsFactors = FALSE)
land.orig <- read.csv("landings_by_gear.csv", sep = ";", stringsAsFactors = FALSE)
inflation <- read.csv("ratio.csv", stringsAsFactors = FALSE)
load("ecovars.orig")
ecovars.orig$year <- as.numeric(as.character(ecovars.orig$year))
```

2 Methods

For simplicity let's call the economic aggregation of fishing operations, fleet segments, and the "biological" metier. For fleet segments the catch device is called "fishing technique", while for metiers is called "gear type". I don't like these names and I think they're adding confusion to an already complex system. For now it doesn't matter.

The analysis was carried out in 3 major steps:

1. Compute the standardized economic variables (fixed costs by vessel, variable costs by unit of effort (kwday) and crew costs by euro of revenue - aka crew share) by gear type, member state, length over all class and year. The variables were computed as a weighted average of the standardized economic variables at the fleet segment level. These maths may need revision, anyway considering one year, one supra region and one vessel length class; if v is the standardized economic variable, T is the transversal or standardizing variable (e.g. effort), i =fleet segment, j =sub region and g =gear type:
$$v_{jg} = \sum_i v_{ijg} \frac{T_{ijg}}{\sum_i T_{gj}}$$
$$v_{ijg} = \frac{E_i}{T_i}$$

2. Fit mixed effects models using fishing technique as a random effect and as fixed effects gear type, member state, length over all class and year.

3. use the models to predict the standardized economic variables by gear type, member state, year and length over all class.

4. Populate FCube fleets' fixed, variable and crewshare slots.

3 Results

3.1 Compute standardized economic variables

3.1.1 Process data

A cluster aggregates segments (e.g. if not many vessels in a segment, they get combined into a cluster).

Add cluster to the eff, land and economic data, allowing us to link datasets later on.

Not all "by" in eff, lnd and eco are in clu so we are missing some clusters, which will be built from fleet segment.

```
# ---------------------------------------------------
# clusters
# ---------------------------------------------------
# Effort
```

```
eff <- left_join(eff.orig, clu.orig[, c("country_code", "year",
    "supra_reg", "fishing_tech", "vessel_length", "cluster")],
    by = c("country_code", "year", "supra_reg", "fishing_tech",
        "vessel_length"))
df0 <- eff[is.na(eff$cluster), ]
df0 <- transform(df0, cluster = paste(supra_reg, fishing_tech,
    vessel_length, sep = ""))
eff <- rbind(eff[!is.na(eff$cluster), ], df0)
rm(df0)

# Landings
lnd <- left_join(land.orig, clu.orig[, c("country_code", "year",
    "supra_reg", "fishing_tech", "vessel_length", "cluster")],
    by = c("country_code", "year", "supra_reg", "fishing_tech",
        "vessel_length"))
df0 <- lnd[is.na(lnd$cluster), ]
df0 <- transform(df0, cluster = paste(supra_reg, fishing_tech,
    vessel_length, sep = ""))
lnd <- rbind(lnd[!is.na(lnd$cluster), ], df0)
rm(df0)

# Economics
eco <- left_join(ecovars.orig[, -1], clu.orig[, c("country_code",
    "year", "supra_reg", "fishing_tech", "vessel_length", "cluster")],
    by = c("country_code", "year", "supra_reg", "fishing_tech",
        "vessel_length"))
df0 <- eco[is.na(eco$cluster), ]
df0 <- transform(df0, cluster = paste(supra_reg, fishing_tech,
    vessel_length, sep = ""))
eco <- rbind(eco[!is.na(eco$cluster), ], df0)
rm(df0)

# -----------------------------------------------------
# subset active vessels and area 27
# -----------------------------------------------------

eco <- subset(eco, supra_reg == "AREA27" & fishing_tech != "INACTIVE" &
    year %in% yrs)
eff <- subset(eff, supra_reg == "AREA27" & fishing_tech != "INACTIVE" &
    year %in% yrs)
lnd <- subset(lnd, supra_reg == "AREA27" & fishing_tech != "INACTIVE" &
    year %in% yrs)

# -----------------------------------------------------
# Correction by inflation
# -----------------------------------------------------

# index - correct up to 2012
infIndex <- subset(inflation[, -4], year < 2013)
infIndex[infIndex$year == 2012, "inflation"] <- 0
infIndex <- infIndex[order(infIndex$year, decreasing = TRUE),
    ]
infIndex <- mutate(group_by(infIndex, country_code), inflation = cumprod(inflation/100 +
    1))

# economics
eco <- merge(eco, infIndex, by.x = c("country_code", "year"),
    by.y = c("country_code", "year"), all.x = TRUE)
```

```
vars2fix <- c("totenercost", "totvarcost", "totdepcost", "totnovarcost",
    "OPR", "totrepcost", "totcrewwage", "totunpaidlab", "totvallandg",
    "totrightscost", "totlandginc", "totrightsinc", "totinvest",
    "tototherinc", "totrights", "totdeprep")
df0 <- subset(eco, variable %in% vars2fix)
df0 <- transform(df0, value = value * inflation)
eco <- rbind(df0, subset(eco, !(variable %in% vars2fix)))

# landings
lnd <- merge(lnd, infIndex, by.x = c("country_code", "year"),
    by.y = c("country_code", "year"), all.x = TRUE)
lnd <- transform(lnd, totvallandgFix = totvallandg * inflation)
```

3.1.2 Compute costs

Sum fixed costs, variable costs, crew wages, effort (kw and days) and capacity over (country_code, year, supra_reg, fishing_tech, vessel_length, cluster).

Note that if one of the cost components is missing (NA), costs are not computed.

```
# ------------------------------------------------------
# compute costs
# ------------------------------------------------------

fixCosts <- c("totdepcost", "totnovarcost", "totrightscost")
varCosts <- c("totenercost", "totvarcost", "totrepcost")
crwCosts <- c("totcrewwage", "totunpaidlab")

df0 <- dcast(eco[, -9], country_code + year + supra_reg + fishing_tech +
    vessel_length + cluster ~ variable)
csts <- df0[, c("country_code", "year", "supra_reg", "fishing_tech",
    "vessel_length", "cluster")]
csts$fCst <- apply(df0[, fixCosts], 1, sum)
csts$vCst <- apply(df0[, varCosts], 1, sum)
csts$cCst <- apply(df0[, crwCosts], 1, sum)
csts$eff <- df0[, "totkwfishdays"]
csts$cap <- df0[, "totves"]
csts$emp <- df0[, "totharmfte"]

# ------------------------------------------------------
# compute landings and effort
# ------------------------------------------------------ Get
# total landings revenue, landings weight and landings price
# by country_code, year, supra_reg, fishing_tech,
# vessel_length, sub_reg, gear_type, cluster For landings we
# are summing over species.
# ------------------------------------------------------

revn <- summarise(group_by(lnd, country_code, year, supra_reg,
    fishing_tech, vessel_length, sub_reg, gear_type, cluster),
    wLnd = sum(totwghtlandg, na.rm = TRUE), rLnd = sum(totvallandgFix,
        na.rm = TRUE), pLnd = sum(totvallandgFix, na.rm = TRUE)/sum(totwghtlandg,
        na.rm = TRUE))
```

3.1.3 Compute standardized economic variables

```
# ======================================================
# Computing indicators per cluster
# ------------------------------------------------------
# Economic data has been summarised by country_code, year,
# supra_reg, fishing_tech, vessel_length, cluster Landings
# and effort data is by country_code, year, supra_reg,
# fishing_tech, vessel_length, cluster, sub_reg, gear_type
# Use cluster field to move from economic data to effort data
# ======================================================

# ------------------------------------------------------
# Variable costs
# ------------------------------------------------------

# compute standardized economic variable

# Rename for moving into eff data
csts$effEcon <- csts$eff

# Join the economic variable cost data with the effort data
# The vCst data is for the cluster, country_code, year
# combination
eff <- left_join(eff, csts[, c("cluster", "country_code", "year",
    "vCst", "effEcon")], by = c("cluster", "country_code", "year"))

# Effort data is present in the effort dataset (duh!)  Sum
# this over cluster / country / year and compare with data
# from Econ data
df0 <- summarise(group_by(eff, cluster, country_code, year),
    effEff = sum(totkwfishdays), effEcon = effEcon[1])

# Put the clustered eff data into eff
eff <- left_join(eff, df0[, c("country_code", "cluster", "year",
    "effEff")])

# Make a combined column of days effort - use Econ, fill in
# missing data with data in Eff
eff$eff <- eff$effEcon
eff[is.na(eff$eff), "eff"] <- eff[is.na(eff$eff), "effEff"]

# Make column of var cost by effort (for cluster / year /
# country) This rate is same across whole cluster (including
# subreg etc)
eff$unitVcst <- eff$vCst/eff$eff
eff$effEcon <- eff$effEff <- NULL

# ------------------------------------------------------ Crew
# costs & share & total revenue from fishing
# ------------------------------------------------------

# compute standardized economic variable

# Add the crewCosts into revn
revn <- left_join(revn, csts[, c("country_code", "year", "cluster",
    "cCst")], by = c("country_code", "year", "cluster"))

# Crew share by cluster
revn <- mutate(group_by(revn, cluster, country_code, year), cShr = cCst/sum(rLnd),
```

```
    totalCcst = cCst, totalRlnd = sum(rLnd))

# -----------------------------------------------------
# Fixed costs
# -----------------------------------------------------

# compute standardized economic variable

# Join the economic variable cost data with the effort data
# The fCst data is for the cluster, country_code, year
# combination
eff <- left_join(eff, csts[, c("cluster", "country_code", "year",
    "fCst", "cap")], by = c("cluster", "country_code", "year"))

# Make column of fix cost by effort (for cluster / year /
# country) This rate is same across whole cluster (including
# subreg etc)
eff$unitFcst <- eff$fCst/eff$cap

# =====================================================
# Computing indicators per gear type NOTE: crossing segments
# and sub regions
# =====================================================

eff <- ddply(eff, .(country_code, year, vessel_length, gear_type),
    function(x) {
        x$vCbar <- weighted.mean(x$unitVcst, x$totkwfishdays,
            na.rm = T)
        x$fCbar <- weighted.mean(x$unitFcst, x$cap, na.rm = T)
        x
    })

revn <- ddply(revn, .(country_code, year, vessel_length, gear_type),
    function(x) {
        x$cSbar <- weighted.mean(x$cShr, x$rLnd, na.rm = T)
        x
    })
```

3.2 Model standardized costs

3.2.1 Prepare datasets

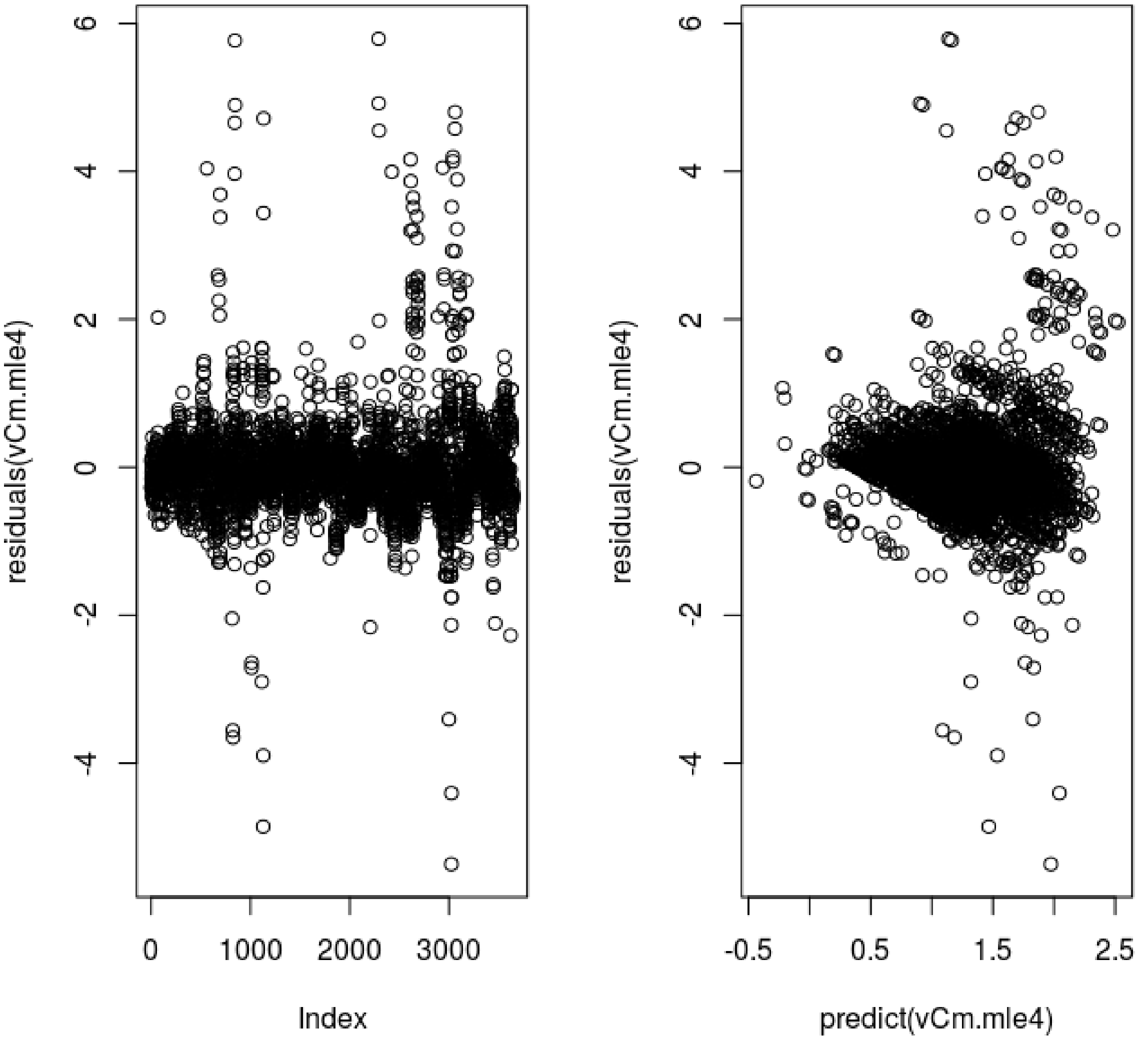
```
# for fixed and variable costs
Cm.df <- as.data.frame(summarise(group_by(eff, cluster, country_code,
    year, vessel_length, fishing_tech, gear_type), eff = eff[1],
    cap = cap[1], vCbar = vCbar[1], fCbar = fCbar[1]))
names(Cm.df) <- c("clt", "ms", "y", "loa", "ft", "gr", "eff",
    "cap", "vCbar", "fCbar")
# remove gears with less than 10 observations, NO and NK
df0 <- table(Cm.df$gr)
v0 <- names(df0)[df0 > 10]
v0 <- v0[!(v0 %in% c("NO", "NK"))]
Cm.df <- subset(Cm.df, gr %in% v0)

# for variable costs(levels set mannualy to meet all
# datasets)
```

```
vCm.df <- subset(Cm.df, vCbar > 0 & !is.na(eff))
vCm.df <- transform(vCm.df, y = as.factor(y), loa = as.factor(loa),
    ms = as.factor(ms), gr = as.factor(gr))
vCm.df <- transform(vCm.df, y = relevel(y, "2012"), loa = relevel(loa,
    "VL1218"), ms = relevel(ms, "GBR"), gr = relevel(gr, "OTB"))

# for fixed costs
fCm.df <- subset(Cm.df, fCbar > 0 & !is.na(cap))
fCm.df <- transform(fCm.df, y = as.factor(y), loa = as.factor(loa),
    ms = as.factor(ms), gr = as.factor(gr))
fCm.df <- transform(fCm.df, y = relevel(y, "2012"), loa = relevel(loa,
    "VL1218"), ms = relevel(ms, "GBR"), gr = relevel(gr, "OTB"))

# for crew share
cSm.df <- as.data.frame(summarise(group_by(revn, cluster, country_code,
    year, vessel_length, fishing_tech, gear_type), twLnd = sum(wLnd,
    na.rm = T), trLnd = totalRlnd[1], tccLnd = totalCcst[1],
    cSbar = cSbar[1]))
names(cSm.df) <- c("clt", "ms", "y", "loa", "ft", "gr", "twLnd",
    "trLnd", "tcCst", "cSbar")
cSm.df <- subset(cSm.df, cSbar < 1 & cSbar > 0 & gr %in% v0)
cSm.df <- subset(cSm.df, !is.na(trLnd))
cSm.df <- transform(cSm.df, y = as.factor(y), loa = as.factor(loa),
    ms = as.factor(ms), gr = as.factor(gr))
cSm.df <- transform(cSm.df, y = relevel(y, "2012"), loa = relevel(loa,
    "VL1218"), ms = relevel(ms, "GBR"), gr = relevel(gr, "OTB"))

# for predictions
nd0 <- as.data.frame(summarise(group_by(eff, country_code, year,
    vessel_length, gear_type), vCbar = vCbar[1], fCbar = fCbar[1],
    idx = paste(country_code, year, vessel_length, gear_type,
        sep = ":")))
names(nd0) <- c("ms", "y", "loa", "gr", "vCbar", "fCbar", "idx")

nd1 <- as.data.frame(summarise(group_by(revn, country_code, year,
    vessel_length, gear_type), rLnd = sum(rLnd, na.rm = T), cSbar = cSbar[1],
    idx = paste(country_code, year, vessel_length, gear_type,
        sep = ":")))
names(nd1) <- c("ms", "y", "loa", "gr", "rLnd", "cSbar", "idx")

nd <- merge(nd0, nd1[, c("rLnd", "cSbar", "idx")], all = TRUE)

# remove gears with less than 10 observations, NO and NK
nd <- subset(nd, gr %in% v0)
nd <- transform(nd, y = as.factor(y), loa = as.factor(loa), ms = as.factor(ms),
    gr = as.factor(gr))
nd <- transform(nd, y = relevel(y, "2012"), loa = relevel(loa,
    "VL1218"), ms = relevel(ms, "GBR"), gr = relevel(gr, "OTB"))
rm(nd0, nd1)
```

3.2.2 Fit lme models

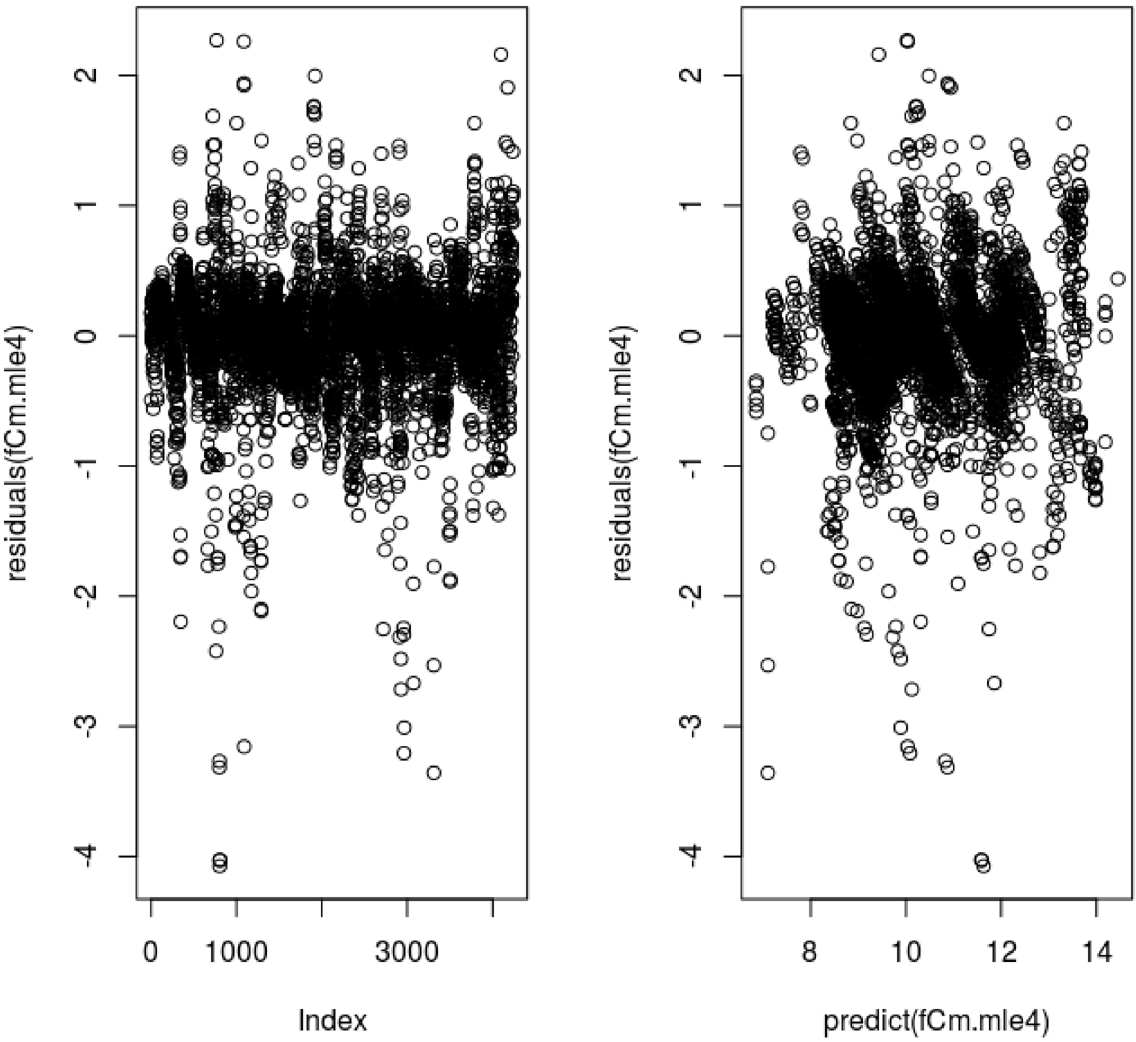
```
# ------------------------------------------------------- Fit
# lme model with log transform to variable costs
# ------------------------------------------------------- fit
# model
```

```
vCm.mle4 <- lmer(log(vCbar) ~ ms + gr + loa + y + (1 | ft), data = vCm.df)

par(mfrow = c(1, 2))
plot(residuals(vCm.mle4))
plot(residuals(vCm.mle4) ~ predict(vCm.mle4))
```



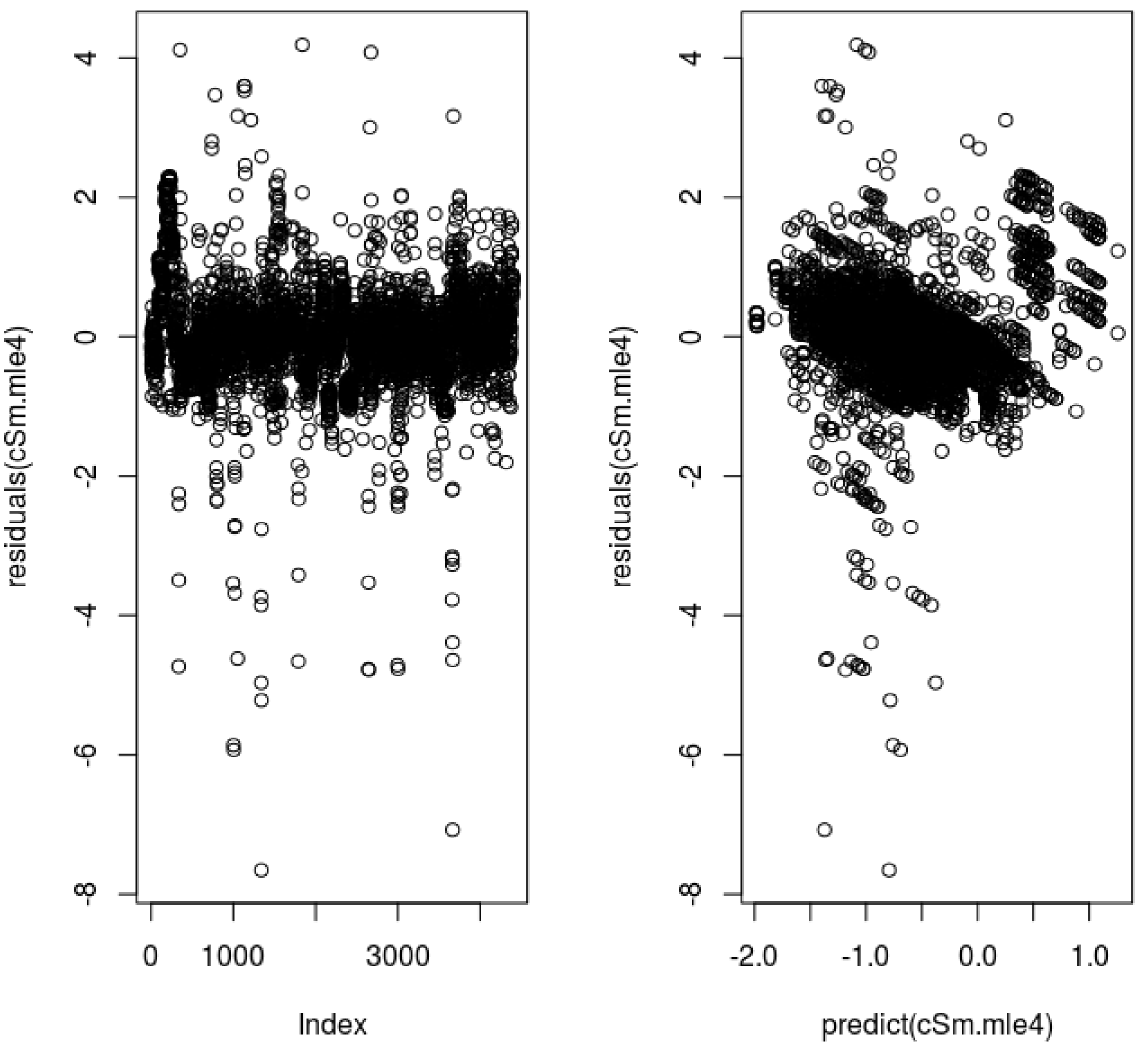

```
# bootstrap
vCm.bs <- bootMer(vCm.mle4, FUN = function(x) predict(x, re.form = ~0,
    type = "response", newdata = nd), 250)

# predict
nd$vCbarPred <- apply(exp(vCm.bs$t), 2, mean)
nd$vCbarVar <- apply(exp(vCm.bs$t), 2, var)
nd$vCbarupp <- apply(exp(vCm.bs$t), 2, quantile, prob = 0.975,
    na.rm = TRUE)
nd$vCbarlow <- apply(exp(vCm.bs$t), 2, quantile, prob = 0.025,
    na.rm = TRUE)

# ------------------------------------------------------ fit
```

```r
# lme model with log transform to fixed costs
# -------------------------------------------------------

# fit model
fCm.mle4 <- lmer(log(fCbar) ~ ms + gr + loa + (1 | ft), data = fCm.df)

par(mfrow = c(1, 2))
plot(residuals(fCm.mle4))
plot(residuals(fCm.mle4) ~ predict(fCm.mle4))
```




```r
# bootstrap
fCm.bs <- bootMer(fCm.mle4, FUN = function(x) predict(x, re.form = ~0,
    type = "response", newdata = nd), 250)

# predict
nd$fCbarPred <- apply(exp(fCm.bs$t), 2, mean)
nd$fCbarVar <- apply(exp(fCm.bs$t), 2, var)
nd$fCbarUpp <- apply(exp(fCm.bs$t), 2, quantile, prob = 0.975,
    na.rm = TRUE)
```

```
nd$fCbarLow <- apply(exp(fCm.bs$t), 2, quantile, prob = 0.025,
    na.rm = TRUE)

# ------------------------------------------------------ fit
# lme model with logit transform to crew share
# ------------------------------------------------------

# fit model
cSm.mle4 <- lmer(logit(cSbar) ~ ms + gr + loa + (1 | ft), data = cSm.df)

par(mfrow = c(1, 2))
plot(residuals(cSm.mle4))
plot(residuals(cSm.mle4) ~ predict(cSm.mle4))
```




```
# bootstrap
cSm.bs <- bootMer(cSm.mle4, FUN = function(x) predict(x, re.form = ~0,
    type = "response", newdata = nd), 250)

# predict
```

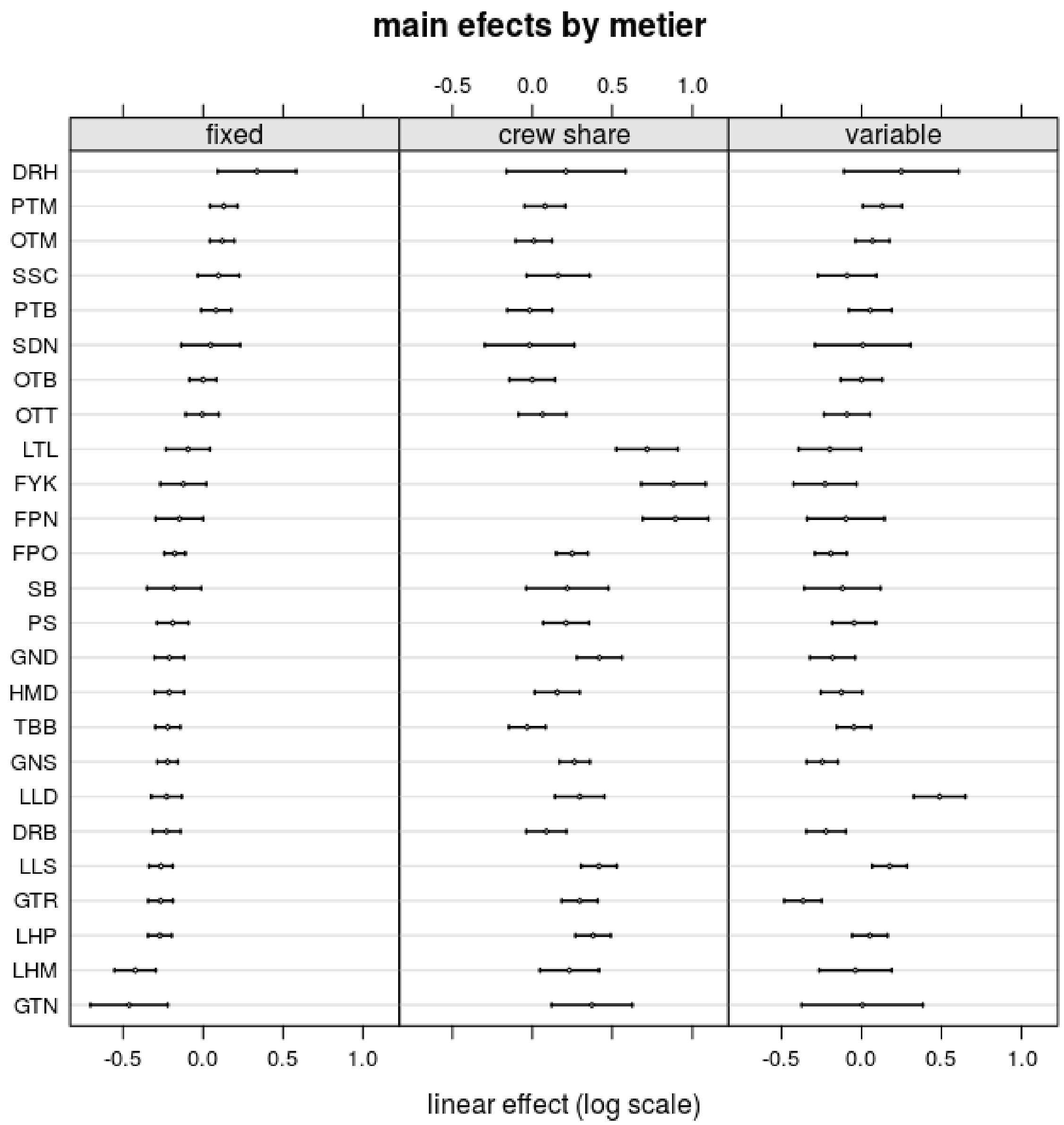
```
nd$cSbarPred <- apply(inv.logit(cSm.bs$t), 2, mean)
nd$cSbarVar <- apply(inv.logit(cSm.bs$t), 2, var)
nd$cSbarUpp <- apply(inv.logit(cSm.bs$t), 2, quantile, prob = 0.975,
    na.rm = TRUE)
nd$cSbarLow <- apply(inv.logit(cSm.bs$t), 2, quantile, prob = 0.025,
    na.rm = TRUE)
```

3.2.3 Factors affecting the costs - fixed effects coefficients

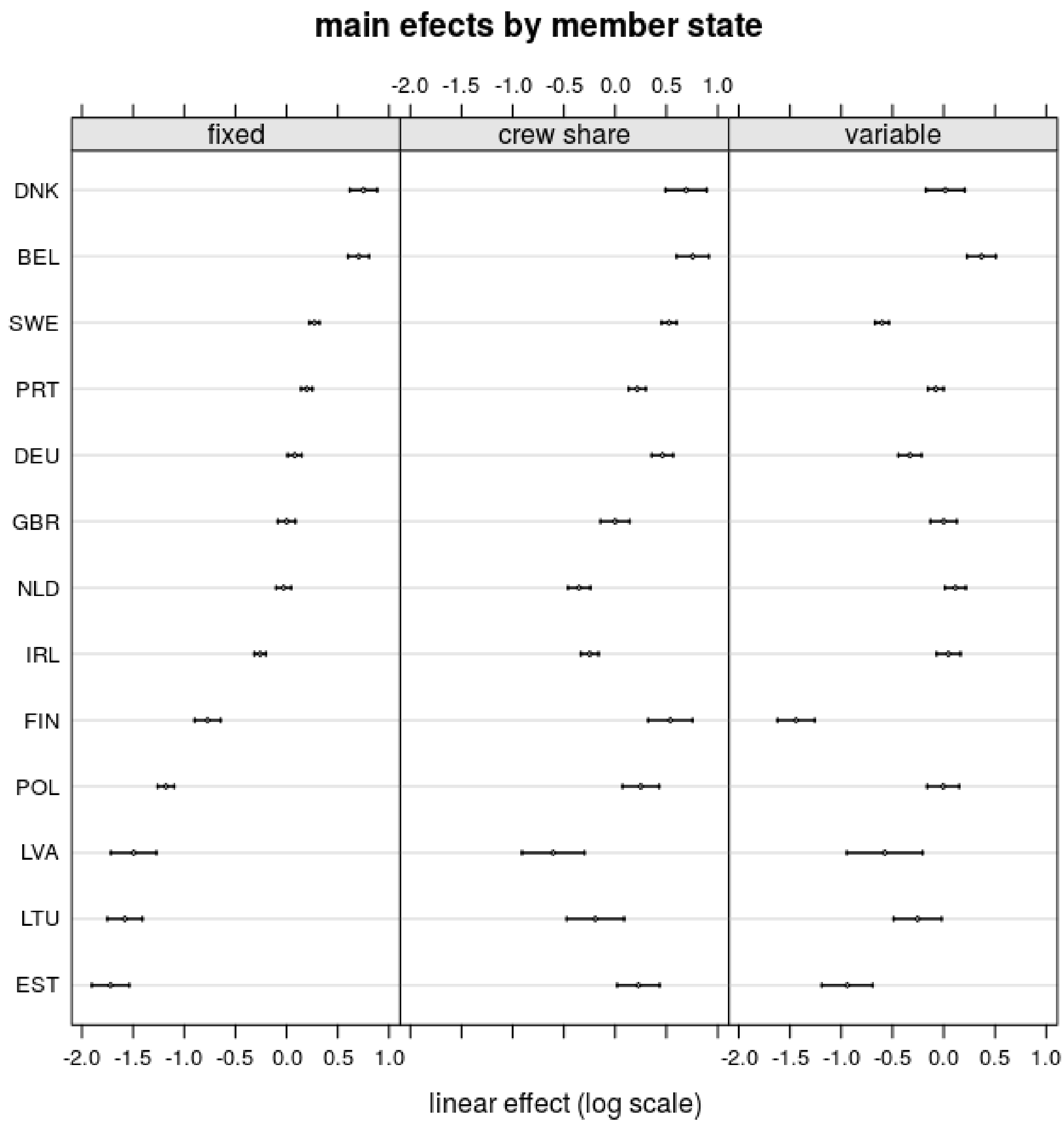
```
fixef.res <- getFixEffRes(fCm.mle4, fCm.df, "fixed")
fixef.res <- rbind(fixef.res, getFixEffRes(vCm.mle4, vCm.df,
    "variable"))
fixef.res <- rbind(fixef.res, getFixEffRes(cSm.mle4, cSm.df,
    "crew share"))
fixef.res <- merge(fixef.res, codes.gr, by.x = "level", by.y = "code",
    all.x = T)
```

```
pset <- list(strip.background = list(col = "gray90"))
pfun <- function(x, y, ...) {
    panel.abline(h = y, col = "gray90", wd = 0.5)
    ll <- length(x)
    x0 <- x[1:(ll/3)]
    y0 <- y[1:(ll/3)]
    x1 <- x[(ll/3 + 1):(2 * ll/3)]
    y1 <- y[(ll/3 + 1):(2 * ll/3)]
    # panel.segments(x0,y0,x1,y1, lwd=1.5)
    panel.arrows(x0, y0, x1, y1, lwd = 1.5, code = 3, angle = 90,
        length = 0.01)
    x <- x[(2 * ll/3 + 1):(ll)]
    y <- y[(2 * ll/3 + 1):(ll)]
    panel.points(x, y, pch = 23, cex = 0.3, col = 1, fill = "white")
}
```

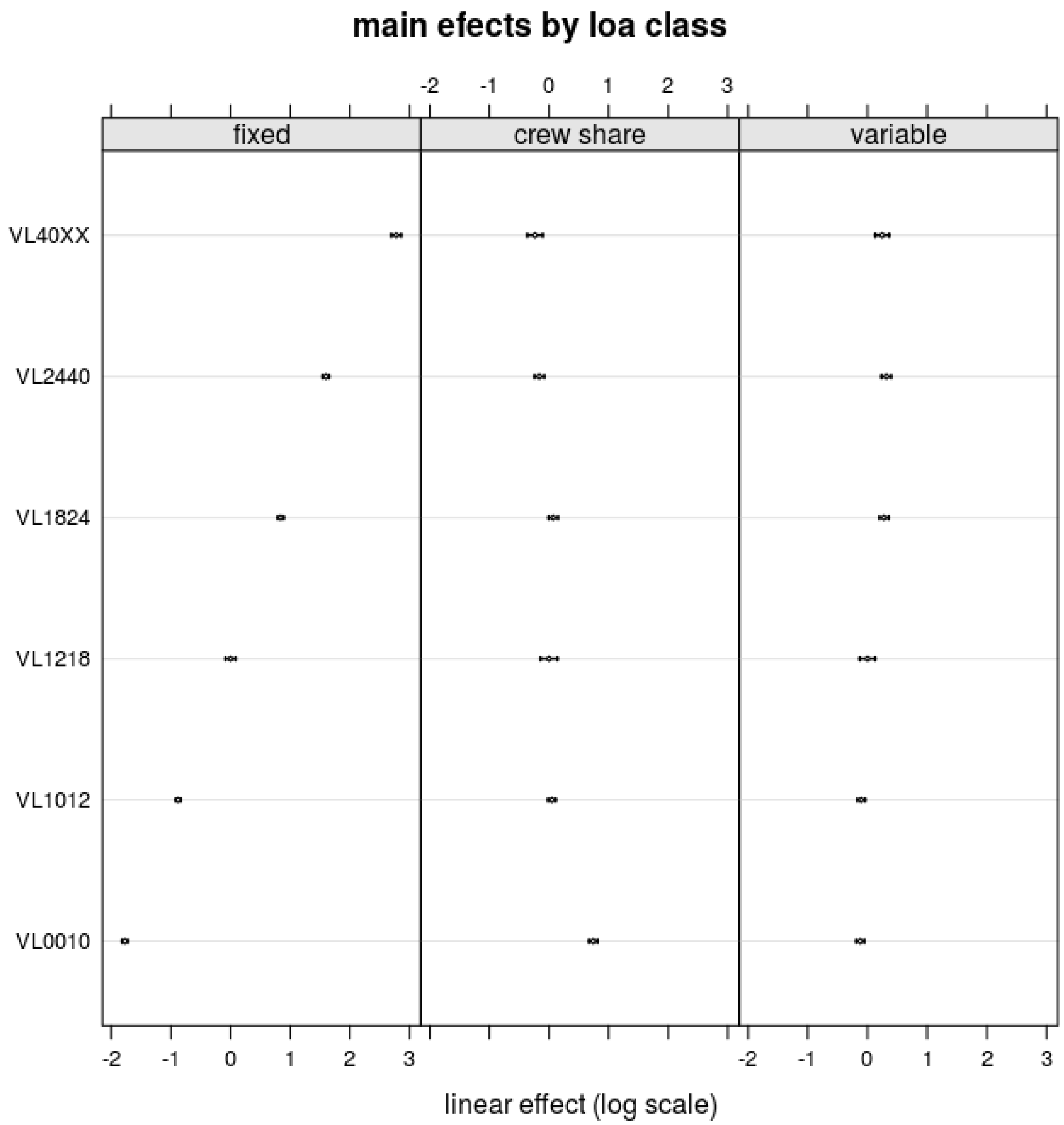
```
df0 <- subset(fixef.res, eff == "gr")
df0$cst <- relevel(factor(df0$cst), "fixed")

df1 <- subset(df0, cst == "fixed")[, c("level", "est")]
names(df1) <- c("level", "sort")
df0 <- merge(df0, df1)

dotplot(reorder(level, sort) ~ low + upp + est | cst, data = df0,
    panel = pfun, par.settings = pset, layout = c(3, 1), xlab = "linear effect (log scale)",
    main = "main efects by metier")
```




```r
df0 <- subset(fixef.res, eff == "ms")
df0$cst <- relevel(factor(df0$cst), "fixed")

df1 <- subset(df0, cst == "fixed")[, c("level", "est")]
names(df1) <- c("level", "sort")
df0 <- merge(df0, df1)

dotplot(reorder(level, sort) ~ low + upp + est | cst, data = df0,
    panel = pfun, par.settings = pset, layout = c(3, 1), xlab = "linear effect (log scale)",
    main = "main efects by member state")
```




```
df0 <- subset(fixef.res, eff == "loa")
df0$cst <- relevel(factor(df0$cst), "fixed")

df1 <- subset(df0, cst == "fixed")[, c("level", "est")]
names(df1) <- c("level", "sort")
df0 <- merge(df0, df1)

dotplot(reorder(level, sort) ~ low + upp + est | cst, data = df0,
    panel = pfun, par.settings = pset, layout = c(3, 1), xlab = "linear effect (log scale)",
    main = "main efects by loa class")
```



4 Adding economics to the FCube fleets

To add economics to FCube it was necessary to map FCube fleets into the standardized dataset fleets. This was done with the table below.

```
library(FLFleet)
load("../fleets/03_NS Making FLFleets_withoutWoS v2_R215_KW.RData")
f3flt <- read.csv("f3flts.csv")
kable(f3flt)
```

f3flt	ms	gr	loa
BE_Beam>=24	BEL	TBB	VL2440
BE_Otter	BEL	OTB	NA
DK_FDF	DNK	NA	NA
DK_Otter<24	DNK	OTB	VL1218
DK_Otter<24	DNK	OTB	VL1824
DK_Otter24-40	DNK	OTB	VL2440
DK_Seine	DNK	NA	NA
DK_Static	DNK	GTN	NA
EN_Beam	GBR	TBB	NA
EN_FDF	GBR	NA	NA
EN_Otter<24	GBR	OTB	VL1218
EN_Otter<24	GBR	OTB	VL1824
EN_Otter>=40	GBR	OTB	VL40XX
EN_Otter24-40	GBR	OTB	VL2440
EN_U10	GBR	NA	VL0010
FR_Beam	NA	TBB	NA
FR_Nets	NA	GTN	NA
FR_Otter>=40	NA	OTB	VL40XX
FR_Otter10-40	NA	OTB	VL1218
FR_Otter10-40	NA	OTB	VL1824
FR_Otter10-40	NA	OTB	VL2440
FR_Otter10-40	NA	OTB	VL1012
FR_U10m	NA	NA	VL0010
GE_Beam>=24	DEU	TBB	VL2440
GE_FDF	DEU	NA	NA
GE_Otter<24	DEU	OTB	VL1218
GE_Otter<24	DEU	OTB	VL1824
GE_Otter>=40	DEU	OTB	VL40XX
GE_Otter24-40	DEU	OTB	VL2440
NL_Beam<24	NLD	TBB	VL1218
NL_Beam<24	NLD	TBB	VL1824
NL_Beam>=40	NLD	TBB	VL40XX
NL_Beam24-40	NLD	TBB	VL2440
NL_Otter	NLD	OTB	NA
NO_Otter<40	NA	OTB	NA
NO_Otter>=40	NA	OTB	VL40XX
NO_Static	NA	GTN	NA
SC_FDF	GBR	NA	NA
SC_Otter<24	GBR	OTB	VL1218
SC_Otter<24	GBR	OTB	VL1824
SC_Otter>=24	GBR	OTB	VL40XX
SC_Otter>=24	GBR	OTB	VL2440
SC_Static	GBR	NA	NA
SC_U10_OTB	GBR	OTB	VL0010
SW_Otter	SWE	OTB	NA
OTH_OTH	NA	NA	NA

Using the mapping the average value for each economic variable was computed for each FCube fleet. The code is not the most elegant ...

```
# merge complete cases
df0 <- merge(nd, f3flt)

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
```

```r
    df0
})

f3flt.eco <- do.call("rbind", lst)

# cases with no loa

df0 <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)) & is.na(f3flt$loa),
    ]
df0 <- merge(nd, df0, by.x = c("ms", "gr"), by.y = c("ms", "gr"))

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
    df0
})

f3flt.eco <- rbind(f3flt.eco, do.call("rbind", lst))

# cases with no gr

df0 <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)) & is.na(f3flt$gr),
    ]
df0 <- merge(nd, df0, by.x = c("ms", "loa"), by.y = c("ms", "loa"))

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
    df0
})

f3flt.eco <- rbind(f3flt.eco, do.call("rbind", lst))

# cases with no gr and no loa

df0 <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)) & is.na(f3flt$gr) &
    is.na(f3flt$loa), ]
df0 <- merge(nd, df0, by.x = c("ms"), by.y = c("ms"))

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
    df0
})

f3flt.eco <- rbind(f3flt.eco, do.call("rbind", lst))

# cases with no ms

df0 <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)) & is.na(f3flt$ms),
    ]
df0 <- merge(nd, df0, by.x = c("gr", "loa"), by.y = c("gr", "loa"))

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
```

```
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
    df0
})

f3flt.eco <- rbind(f3flt.eco, do.call("rbind", lst))

# cases with no ms and no loa

df0 <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)) & is.na(f3flt$ms) &
    is.na(f3flt$loa), ]
df0 <- merge(nd, df0, by.x = c("gr"), by.y = c("gr"))

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
    df0
})

f3flt.eco <- rbind(f3flt.eco, do.call("rbind", lst))

# cases with no ms and no gr

df0 <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)) & is.na(f3flt$ms) &
    is.na(f3flt$gr), ]
df0 <- merge(nd, df0, by.x = c("loa"), by.y = c("loa"))

lst <- lapply(split(df0, as.character(df0$f3flt)), function(x) {
    df0 <- t(as.data.frame(apply(x[, c("vCbarPred", "fCbarPred",
        "cSbarPred")], 2, mean, na.rm = T)))
    rownames(df0) <- x$f3flt[1]
    df0
})

f3flt.eco <- rbind(f3flt.eco, do.call("rbind", lst))

# cases with nothing (OTH_OTH)
df0 <- t(as.data.frame(apply(nd[, c("vCbarPred", "fCbarPred",
    "cSbarPred")], 2, mean, na.rm = T)))
rownames(df0) <- f3flt[!(f3flt$f3flt %in% rownames(f3flt.eco)),
    "f3flt"]
f3flt.eco <- rbind(f3flt.eco, df0)
```

And finally added to the relevant FCube fleet.

```
# populating the FLFleet objects

fleets <- lapply(fleets, function(x, eco = f3flt.eco) {
    fcost(x) <- capacity(x) * eco[rownames(eco) == name(x), "fCbarPred"]
    fcost(x)[fcost(x) <= 0] <- NA
    effort(x)[effort(x) <= 0] <- NA
    crewshare(x) <- eco[rownames(eco) == name(x), "cSbarPred"]
    for (i in names(x@metiers)) {
        vcost(metiers(x)[[i]]) <- effshare(metiers(x)[[i]]) *
            effort(x) * eco[rownames(eco) == name(x), "vCbarPred"]
    }
    x
```

```
})

save(fleets, file = "../fleets/03_NS Making FLFleets_withoutWoS v3_R311_KWECON.RData")
```

5 Dataset with predictions

The final dataset variables definition is below:

- "idx" - row index
- "ms" - member state
- "y" - year
- "loa" - vessel length-over-all
- "gr" - gear, level 4 of DCF
- "eff" - effort in days at sea
- "vCbar" - variable costs by unit of effort
- "fCbar" - fixed costs by unit of effort
- "eCbar" - energy costs by unit of effort
- "tCbar" - total costs by unit of effort
- "rLnd" - revenue from landings
- "cSbar" - crew share (crew costs over revenue from landings)
- "vCbarPred" - variable costs by unit of effort (model prediction)
- "vCbarVar" - variable costs by unit of effort (model prediction variance)
- "vCbarupp" - variable costs by unit of effort (model prediction 0.975 quantile, upper confidence interval)
- "vCbarlow" - variable costs by unit of effort (model prediction 0.025 quantile, lower confidence interval)
- "fCbarPred" - fixed costs by unit of effort (model prediction)
- "fCbarVar" - fixed costs by unit of effort (model prediction variance)
- "fCbarupp" - fixed costs by unit of effort (model prediction 0.975 quantile, upper confidence interval)
- "fCbarlow" - fixed costs by unit of effort (model prediction 0.025 quantile, lower confidence interval)
- "cSbarPred" - crew share (model prediction)
- "cSbarVar" - crew share (model prediction variance)
- "cSbarupp" - crew share (model prediction 0.975 quantile, upper confidence interval)
- "cSbarlow" - crew share (model prediction 0.025 quantile, lower confidence interval)
- "eCbarPred" - energy costs by unit of effort (model prediction)
- "eCbarVar" - energy costs by unit of effort (model prediction variance)
- "eCbarupp" - energy costs by unit of effort (model prediction 0.975 quantile, upper confidence interval)

- "eCbarlow" - energy costs by unit of effort (model prediction 0.025 quantile, lower confidence interval)
- "tCbarPred" - total costs by unit of effort (model prediction)
- "tCbarVar" - total costs by unit of effort (model prediction variance)
- "tCbarupp" - total costs by unit of effort (model prediction 0.975 quantile, upper confidence interval)
- "tCbarlow" - total costs by unit of effort (model prediction 0.025 quantile, lower confidence interval)

ANNEX VI - TOTAL EMPLOYMENT AND DEPENDENCY ON THE "BIG 6 PLUS NEPHROPS" IN THE NORTH SEA OVER AREA 27

AER fleet segments	Employment in the fleet segment (number of employees)	Value of Big 7 in the NS compared to overall value of landings of the fleet
DEU AREA27 DTS VL2440°	55	80%
DEU AREA27 DFN VL1218°	16	74%
DNK AREA27 DTS VL0010°	6	72%
DEU AREA27 TBB VL2440	45	70%
DNK AREA27 PGP VL1218°	70	68%
NLD AREA27 TBB VL40XX°	734	67%
BEL AREA27 DTS VL1824	36	67%
DNK AREA27 PMP VL1824°	46	65%
NLD AREA27 TBB VL2440°	216	64%
NLD AREA27 DTS VL1824°	73	62%
DNK AREA27 DTS VL1218°	248	59%
DNK AREA27 DTS VL1824°	193	56%
BEL AREA27 TBB VL1218°	10	52%
GBR AREA27 DTS VL1824	1080	52%
DNK AREA27 PMP VL1218°	82	49%
SWE AREA27 DTS VL1012	111	49%
GBR AREA27 DTS VL2440	798	48%
BEL AREA27 TBB VL1824°	97	48%
GBR AREA27 TBB VL2440	304	45%
DEU AREA27 DTS VL1824°	69	44%
DNK AREA27 PMP VL0010°	44	43%
DNK AREA27 DTS VL2440°	146	41%
GBR AREA27 DTS VL0010	601	40%
DNK AREA27 PMP VL1012°	41	38%
SWE AREA27 DTS VL1218	156	35%
FRA AREA27 DFN VL1012°	579	33%
FRA AREA27 DTS VL40XX°	168	33%
DEU AREA27 DFN VL2440	77	32%
NLD AREA27 DTS VL2440	152	31%
GBR AREA27 DTS VL40XX	203	31%
BEL AREA27 TBB VL2440°	166	31%
GBR AREA27 DFN VL0010	1011	29%
DNK AREA27 PGP VL1012°	47	27%
DNK AREA27 PGP VL0010°	213	24%
SWE AREA27 DTS VL1824	152	23%
BEL AREA27 DTS VL2440°	33	21%
FRA AREA27 MGP VL0010°	21	21%
NLD AREA27 TBB VL1824°	586	21%
GBR AREA27 DTS VL1218	971	21%
NLD AREA27 PG VL0010	359	20%
NLD AREA27 DTS VL0010	47	18%

GBR AREA27 TBB VL0010	58	17%
DNK AREA27 DTS VL1012°	11	16%
GBR AREA27 TBB VL1218	128	16%
GBR AREA27 PGP VL0010	214	13%
DEU AREA27 DTS VL40XX°	217	12%
FRA AREA27 DFN VL0010°	427	11%
DNK AREA27 DTS VL40XX°	54	10%
FRA AREA27 DFN VL1218°	330	10%
FRA AREA27 DTS VL0010	133	9%
DNK AREA27 TBB VL1824°	43	7%
FRA AREA27 DTS VL1012	391	6%
GBR AREA27 DFN VL1012	60	6%
DNK AREA27 TBB VL1218°	25	5%
FRA AREA27 DTS VL1824	783	4%
SWE AREA27 DTS VL2440	293	4%
DEU AREA27 DTS VL1218°	29	4%
FRA AREA27 DTS VL2440	423	3%
GBR AREA27 HOK VL0010	860	3%
FRA AREA27 DTS VL1218	619	2%
GBR AREA27 TBB VL1824	124	2%
FRA AREA27 DFN VL1824°	1112	2%
GBR AREA27 FPO VL0010	2846	2%
GBR AREA27 DFN VL2440	144	2%
FRA AREA27 PGP VL0010°	87	1%
FRA AREA27 FPO VL0010°	431	1%
FRA AREA27 PMP VL0010°	104	1%
FRA AREA27 DRB VL0010°	112	1%
GBR AREA27 DFN VL1218	77	0%
GBR AREA27 FPO VL1012	478	0%
GBR AREA27 FPO VL1218	305	0%
FRA AREA27 HOK VL0010	313	0%
DEU AREA27 TBB VL1218°	195	0%
FRA AREA27 MGO VL0010°	125	0%

ANNEX VII – CODES AND ACRONYMS

CODES

COUNTRIES CODES

Alpha 3 code	*Other codes used*	*Contry name*
BEL	be	Belgium
DEU	de / ge	Germany
DNK	dk	Denmark
FRA	fr	France
GBR	GB	United Kingdom
	en	*England*
	sc	*Scotland*
NLD	nl	Netherlands
SWE	sw	Sweden
	no	Norway

FLEETS CODES USED/FCUBE FLEETS

Beam>=24	Beam trawlers >=24 m length
Beam>=40	Beam trawlers >=40 m length
Beam24-40	Beam trawlers 24-40 m length
fdf	Vessels involved in fully documented fishery
nets	Fleet using nets
oth	Other fleets
Otter<24	Fleet using otter trawls <24 m length
Otter>=40	Fleet using otter trawls >=40 m length
Otter10-40	Fleet using otter trawls 10-40 m length
Otter24-40	Fleet using otter trawls 24-40 m length
Seine	Seiners
Static	fleet using static gears
U10m	vessels <10 m length

SPECIES CODES USED

anf	Anglerfishes nei
cod	Cod
had	Haddock
hal	Halibut
her	Herring
hke	Hake
jax	Jack and horse mackerels nei
mac	Mackerel
nep	Nephrops

nop	Nethrops
ple	Plaice
pok	Saithe(=Pollock)
san	Sandeels
shr	Shrimps
sol	Sole
whg	Whiting

DCF CODES

FISHING_TECHNIQUE

DFN	Drift and/or fixed netters
DRB	Dredgers
DTS	Demersal trawlers and/or demersal seiners
FPO	Vessels using pots and/or traps
HOK	Vessels using hooks
MGO	Vessel using other active gears
MGP	Vessels using polyvalent active gears only
PG	Vessels using passive gears only for vessels < 12m
PGO	Vessels using other passive gears
PGP	Vessels using polyvalent passive gears only
PMP	Vessels using active and passive gears
PS	Purse seiners
TM	Pelagic trawlers
TBB	Beam trawlers

VESSEL_LENGTH classes

VL0010	Vessel between 0 meters and 10 meters in length.
VL1012	Vessel between 10 meters and 12 meters in length.
VL1218	Vessel between 12 meters and 18 meters in length.
VL1824	Vessel between 18 meters and 24 meters in length.
VL2440	Vessel between 24 meters and 40 meters in length.
VL40XX	Vessel greater than 40 meters in length.

FISHING GEAR

DRB	Boat dredges
DRH	Hand dredges
FPN	Stationary uncovered pound nets
FPO	Pots
FYK	Fyke nets

GNC	Encircling gillnets
GND	Driftnets
GNS	Set gillnets (anchored)
GTN	Combined gillnets-trammel nets
GTR	Trammel nets
HMD	Mechanised dredges including suction dredges
LA	Lampara nets
LHM	Handlines and pole-lines (mechanised)
LHP	Handlines and pole-lines (hand-operated)
LLD	Drifting longlines
LLS	Set longlines
LNB	Boat-operated lift nets
LNS	Shore-operated stationary lift nets
LTL	Troll lines
MIS	Miscellaneous Gear
NK	NOT KNOWN*
NO	NO GEAR
OTB	Bottom otter trawl
OTM	Midwater otter trawl
OTT	Otter twin trawl
PS	Purse seines
PTB	Bottom pair trawl
PTM	Pelagic pair trawl
SB	Beach seines
SDN	Danish seines
SPR	Pair seines
SSC	Scottish seines
SV	Beach and boat seines
TBB	Beam trawl

AREA27 Baltic Sea, North Sea, Eastern Arctic, North Atlantic.

ACRONYMS

CFP - Common Fisheries Policy

ICES - International Council for the Exploration of the Sea

MSY – Maximum sustainable yield

CPUE – Catch per unit of effort

TAC – Total Allowable Catch

STECF - Scientific, Technical and Economic Committee for Fisheries

SG-MOS – Sub-group on management objectives and strategies

NS - North Sea

HCR – Harvest Control Rules

MAP – Multi annual plan

EwE - Ecopath with Ecosim model

LO - Landings obligation

AER – Annual economic report

FTE - Full Time Equivalent

“Big7” - cod, haddock, whiting, plaice, sole, saithe, and nephrops

FMSY – fishing mortality that provides maximum sustainable yeald

SSB – Spawning stock niomass

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